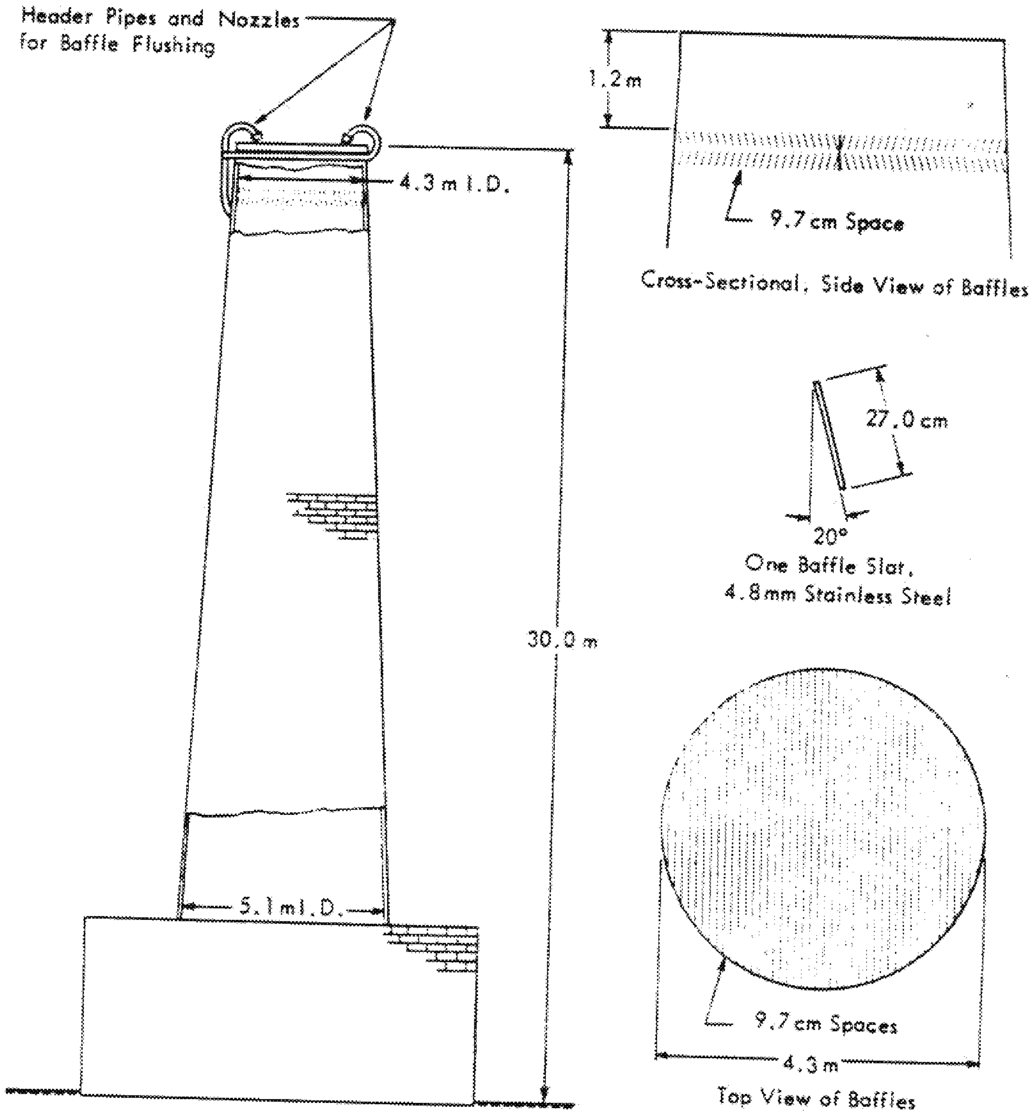

a/ Dimensions supplied by Armco Steel Corporation 34/

Figure 11. A circular quench tower, Armco - Middletown.a/

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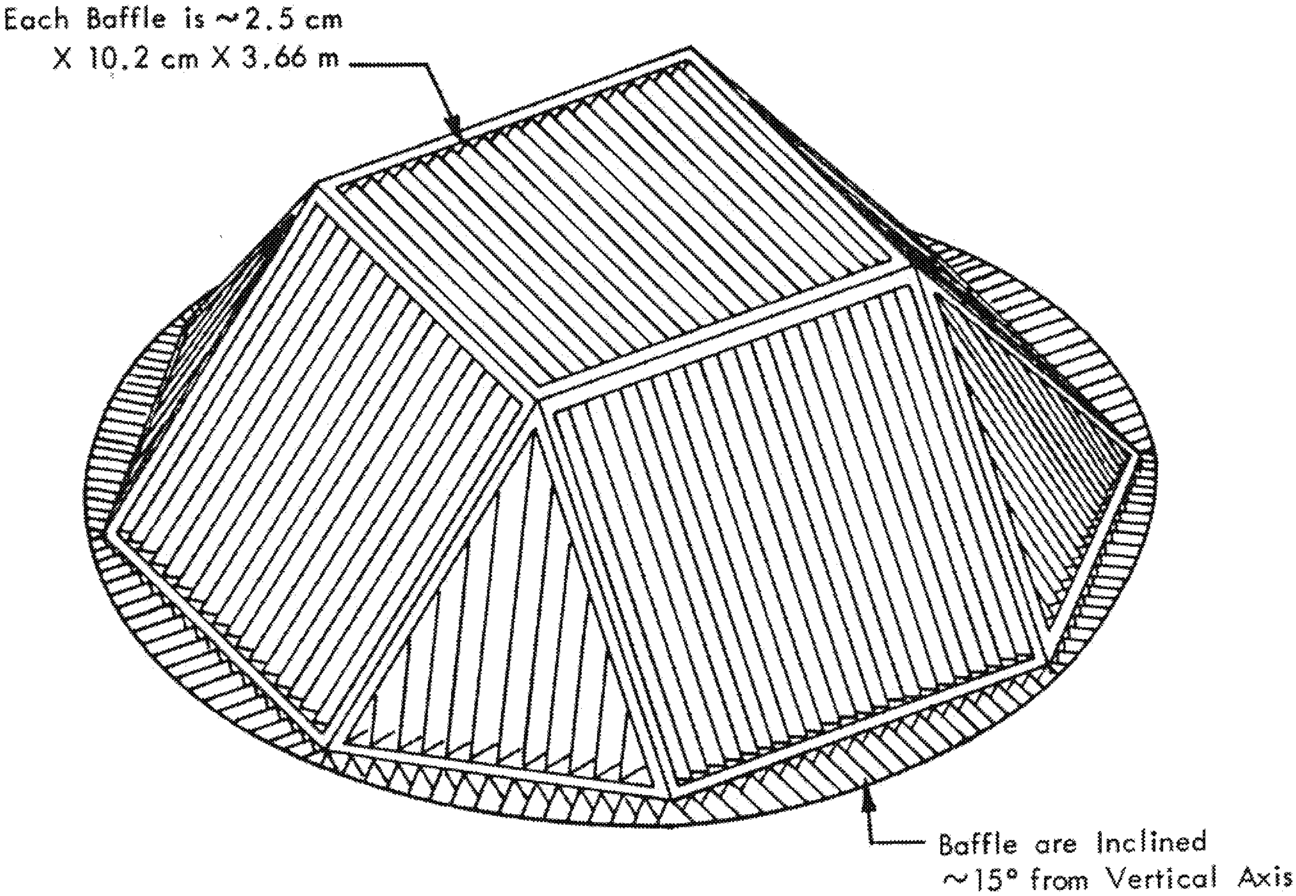
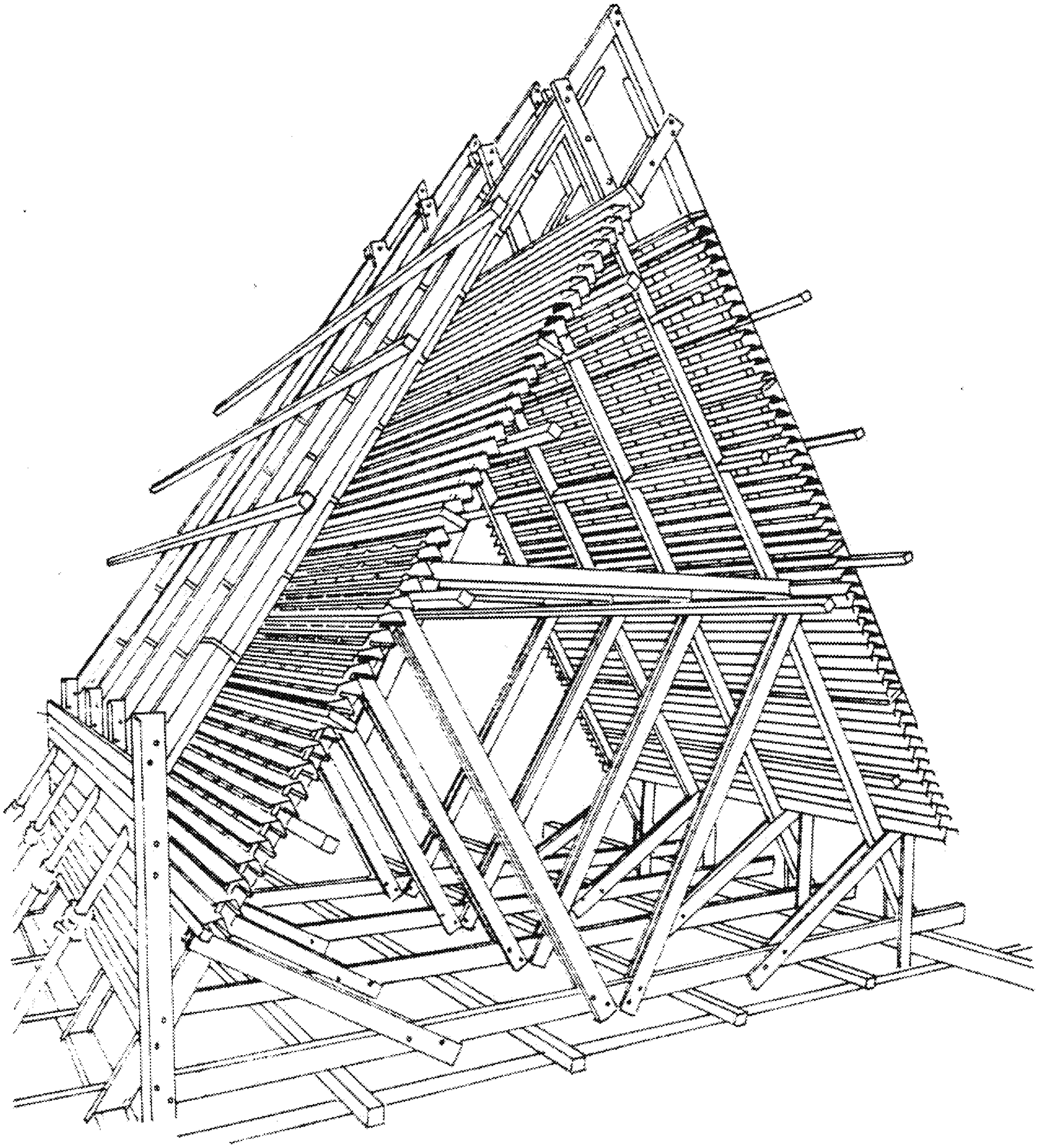


BAFFLES IN QUENCH TOWER FOR
BATTERY NO. 11, INLAND STEEL[a/]

[a/] Dimensions supplied by the Inland Steel Company

Figure 12. Baffles in quench tower for battery No. 11, Inland Steel.[a/]



[a] Adapted from reference 8.

Figure 13. Firma Carl Still baffles.[a]

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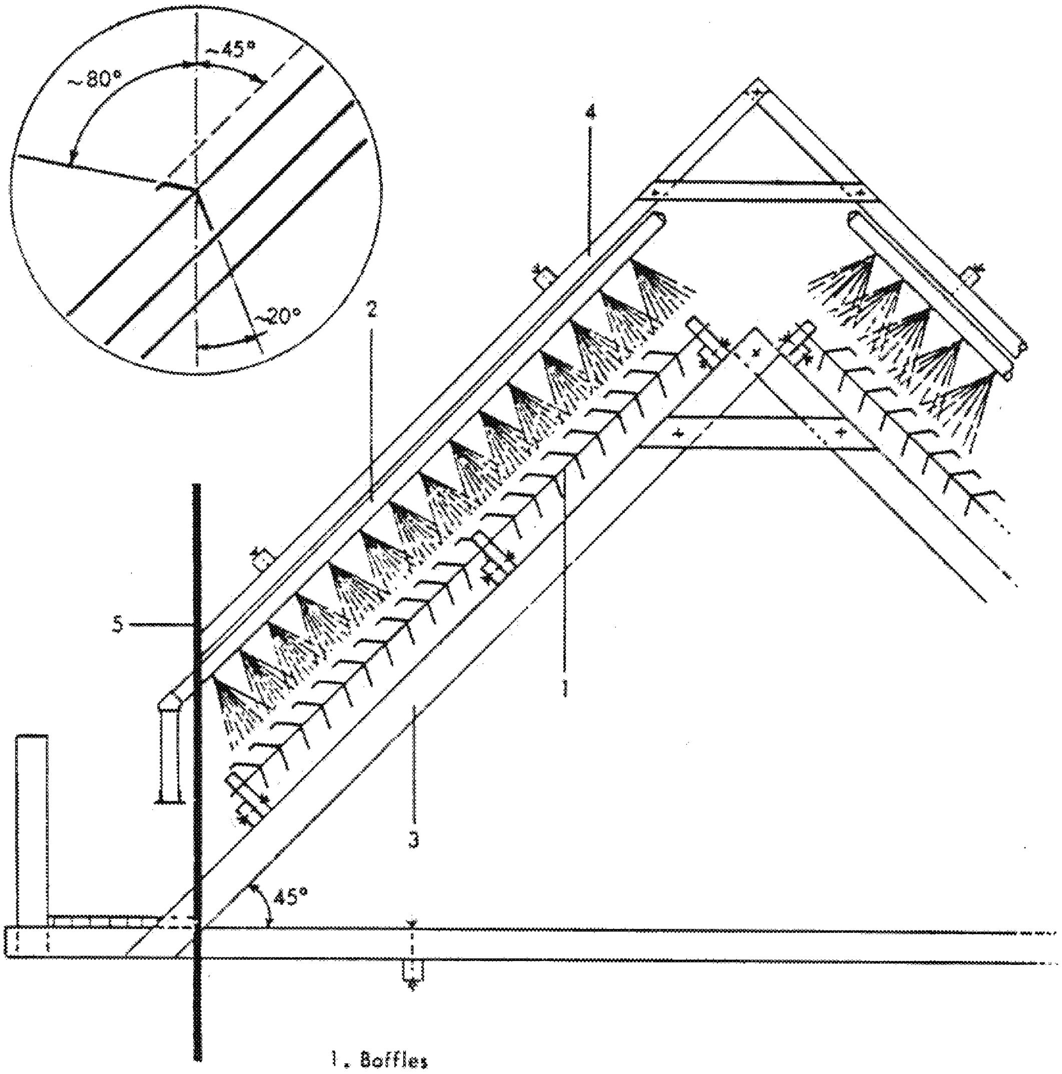


1. Baffles
2. Flushing Lines
3. Supporting Structure for the Baffles
4. Supporting Structure for the Flushing Pipes
5. Quench Tower Wall

a/ Adapted from reference 8.

Figure 14. Firma Carl Still baffles, end view.a/

3.2.1.3 Height of Baffle Installation - Height of baffle installation varies from plant to plant. However, agreement seems to have been reached by those active in this area of design, and all new towers and mist eliminators located were found to have their baffles positioned as high as possible.[11,30]

3.2.1.4 Maintenance - The maintenance of quench tower baffles consists of cleaning the baffles regularly. In most towers, this job is accomplished through the use of overhead sprays. Figures 11 and 12 contain illustrations showing typical cleaning sprays arrangements. The frequency of baffle flushing was found to vary from once after each quench to once every month.[11,35] Clean water is used in these sprays when the nozzles in use are small enough to clog easily.

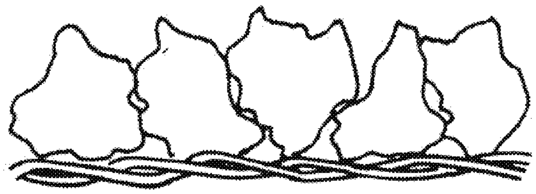
3.2.2 Coke Trays and Wedgewire Screen Baffles

The literature contains references to two uncommon types of baffle or baffle-like devices: coke trays and wedgewire screen baffles (note Figure 15).

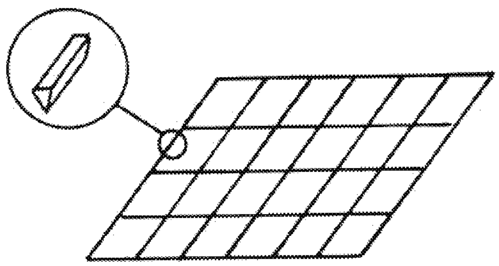
One site was located where coke trays were employed as a quench tower emission control measure, namely, the Alabama Byproducts Corporation in Birmington, Alabama. Chunks of coke 6.5 to 9.0 cm (2.5 to 3.5 in.) in diameter were placed on wire mesh trays in one of Alabama Byproduct's towers for a brief period of time. The method proved to be impractical. The spaces between the pieces of coke rapidly filled with particulate matter and excessive back pressure developed interferring with the proper operation of the quench station. Judging from this reported bad experience and the general absence of similar practices at other plants, coke trays are apparently not practical for controlling quench tower emission.[7,36]

The use of wetted wedgewire screen baffles was reported 18 years ago in a British plant, the Margam Works of the Steel Company of Wales, Ltd. Square sections of the screen, which consisted of hot-dip galvanized mild steel, were arranged in two opposed layers of baffles inclined 65 degrees from a vertical axis. Each square measured 1.2 m (4 ft) on a side. The mesh size was 2 mm (0.08 in.). The tower stood 19.5 m (64 ft) tall and had a cross-sectional area of 111 m^2 (1,200 ft^2). The baffles were positioned in the lower half of the tower immediately above the quenching spray and just below a network of finer sprays which cleaned the screens and helped wash the larger particles out of the quenching plume.[6]

Significant "grit" reduction ($\sim$80%) was claimed as a result of the wedgewire screen system. However, the absence of such methodology in more current usage indicates that the design in question did not prove workable. In the original research, wedgewire screen was selected because it had the longest life of the available materials, but the actual lifetime of these screens is not specified.[6] The corrosive atmosphere of a quench tower flue would be expected to do extensive damage to the grade of metal employed. Apparently, this factor and/or some other problems have discouraged the use of wedgewire screens during



Pieces of Coke
Supported on Wire Mesh



Wedge Wire Screen Used as a Baffle
Stat (Arranged as Opposed Louvers)

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[a] Adapted from reference 31.

Figure 15. Experimental baffle-like devices.[a]

the time period since the cited experiment. No references to the application of this technique after the initial demonstration in 1960 were found in the course of this study.

3.2.3 Back Sprays

Another approach to reducing quenching emissions involves the use of a back spray system to scrub the quenching plume. Although this methodology is not used in this country, references to towers with these back sprays are evidence in West German literature.[5]

Figure 16 illustrates three general quench tower designs which show the manner in which this technology is employed. In most cases, steps are taken to prevent the back spray water from contacting the coke and raising the moisture content of the final product. The example shown in Figure 16a accomplishes this end by way of an offset tower design in which the path of the back spray water is completely off to one side of the coke quench car. The example shown in Figure 16b utilizes a large trap above the quench car which collects the back spray wash water. Figure 16c shows a conventional tower to which a back spray apparatus has been added. In this last case, the back spray is only utilized during the first 20 sec of the quench--the period of greatest particulate production. With proper adjustment of the total quench water used, the desired moisture level in the product may still be achieved.[5]

West German studies indicate that particulate emissions may be reduced by two-thirds when back sprays are applied to quenching plumes.[5] However, one German company does not recommend back sprays, possible because of increased carryover of droplets or mist from the quench tower.* This study did not reveal any plants in the U.S. that employ this technique.

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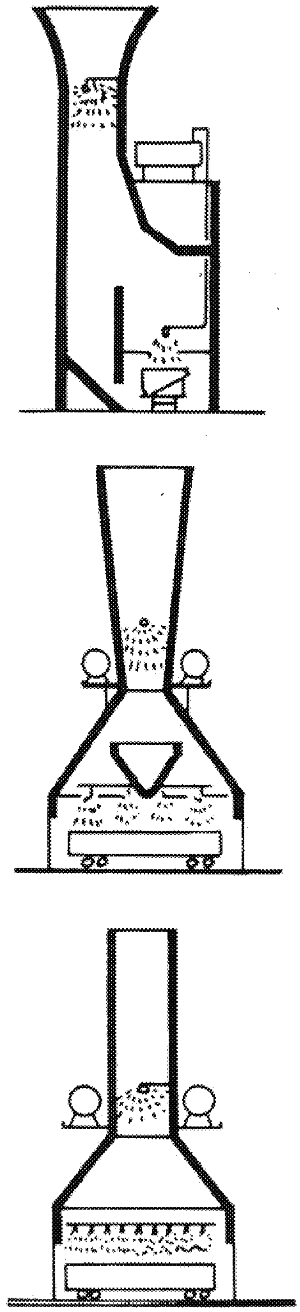
* Private communication with the EPA project officer (Mr. Naum Georgieff).



a. Offset Tower

b. Expanding Tower with a Trap for Back Spray Drainage Above the Quench Car

c. Conventional Tower with an Add-On Back Spray System

a/ Adapted from reference 5.

Figure 16. Back spray designs.[a]

4.0 ANALYSIS OF DATA ON EMISSIONS AND EFFECTIVENESS OF CONTROL METHODS

4.1 TECHNIQUES FOR QUANTIFYING EMISSIONS

One of the greatest deficiencies in assessment of quench tower emissions is the lack of an adequate measurement technique. Although several sampling techniques have been utilized, limited confidence can be placed in the accuracy of some of the methods. Sampling inaccuracies may result from all of the factors described below.

Several factors inherent to the quenching operation contribute to sampling difficulties. First, most quenching operations are intermittent and of short duration. A single quench lasts only 1 to 3 min with periods of 10 to 30 min between quenches. It is difficult to collect adequate samples during a single quench due to this short time period.

The necessity of sampling more than one quench operation makes comparison of the effect of process parameters upon emissions difficult. Within any given quench, there are extreme variations in emission stream properties. Both velocity and temperature vary significantly over short periods of time. In addition, ambient weather conditions cause fluctuation of stack conditions even within a single quench. Finally, the extreme amounts of moisture present as both vapor and liquid cause sampling difficulties.

Several methods of quench tower sampling have been examined. These can be divided into four basic types: (a) attempted isokinetic; (b) a system suggested by German Guidelines VDI-2303; (c) greased plate sampling; and (d) grab samples. Each of these methods is described below with an analysis of possible difficulties involved in each method.

4.1.1 Isokinetic Sampling

Essentially, all isokinetic sampling systems consist of a probe, a device to capture the particulate, and some type of pump to draw gases into the sampler. The capture devices used on quench tower samplers consist of cyclones, filters, and impinger trains. A typical isokinetic sampling system for particulate emissions is shown in Figure 17. The sampling train is used to determine pollutant concentration. This is combined with stack velocity and cross-sectional area to determine emissions.

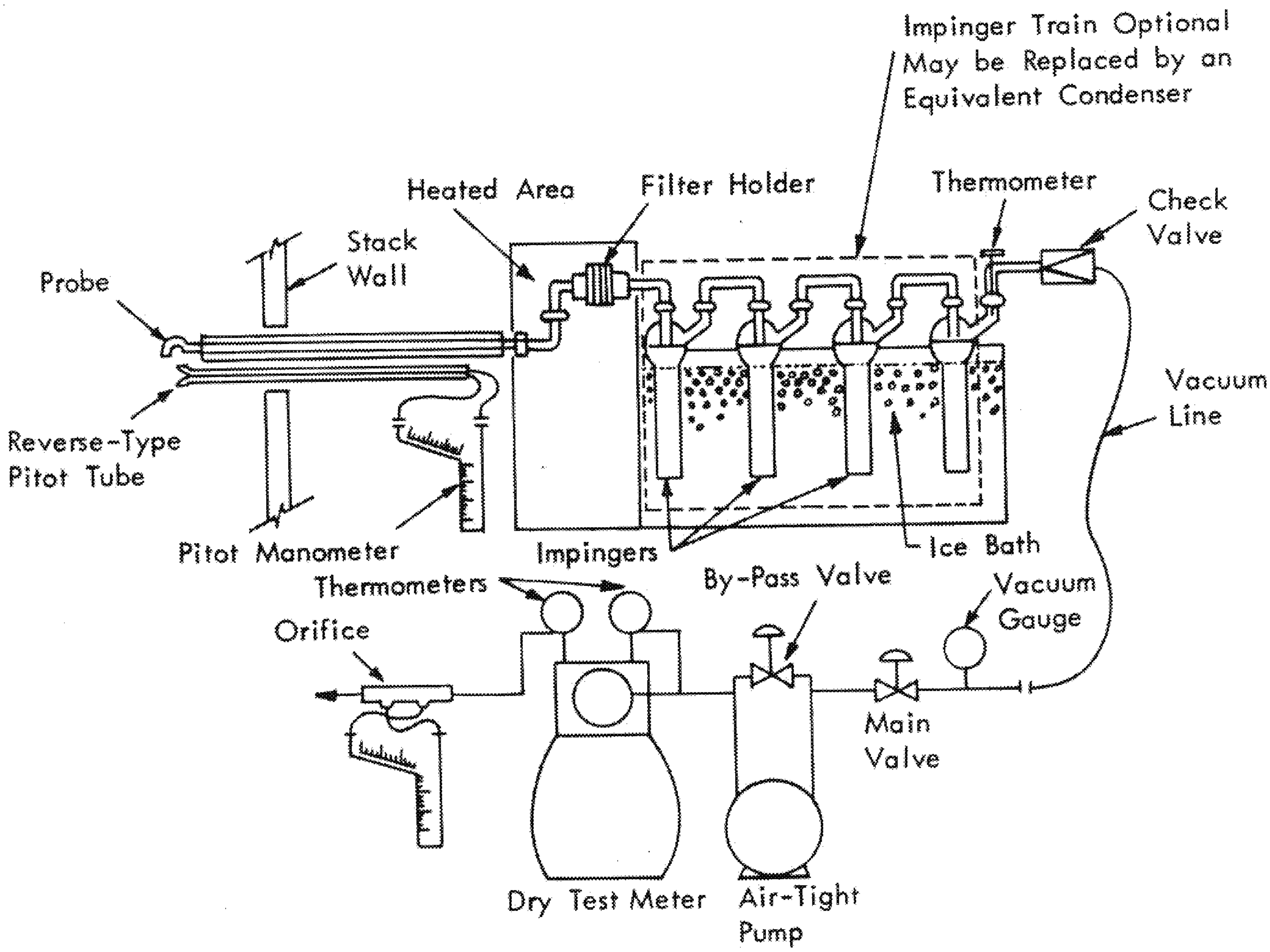


Figure 17. Particulate - sampling train.

When used to determine emissions from a stack, an isokinetic sampling train may collect emissions at a single point or at several points within the stack. If single point sampling is used, it is assumed that the emissions sampled are representative of the emissions throughout the stack. For an emissions stream as variable as that in a coke quench tower, this asumption is highly suspect. Difficulties are also inherent in multiple point sampling. When results from a multipoint sample are used, it is assumed that the relative amount and composition of emissions collected at any given point are consistent throughout the test. However, observations indicate that an emissions stream from a quench tower varies greatly from quench to quench. Hence, it is likely that emissions sampled at one point are not necessarily representative of emissions through that point for the duration of the test. In addition to these difficulties, the extreme variation in stack velocity, both spatial and temporal, make accurate determination of average velocities difficult.

Despite the shortcomings mentioned above, isokinetic sampling is the most reliable method of sampling quench towers. Data from isokinetic tests are considered to be more reliable than those from other tests.

4.1.2 German Guidelines VDI-2303

As a part of the document on restriction of emissions from quenching operations, the VDI Commission "Reinhaltung der Luft" developed a procedure for sampling emissions from coke quench towers. The induced flow system is described below.

For the assessment of dust emissions during quenching operations, a sampling stream of the vapors is conducted through the sampler, where the dust settles (Figure 18). The sampler is made of zinc sheet iron and has a wall thickness of approximately 0.5 mm.

The quenching vapors reach the sampler, which contains a flow-directing baffle plate, through the inlet bend and leave through the outlet socket above the baffle plate. The opening of the outlet socket is covered with a fabric (e.g., gauze) with a very low flow resistance. The sampler is handled by a steel pipe, to which an extension can be fitted. The sampler is emptied through a frontal opening, tightly closed by a gasketed lid.

The dust is separated by centrifugal forces resulting from the change in the flow direction, and by settling forces due to a reduction of the flow velocity, as well as by the filter effect of the fabric.

The samples are taken at the outlet of the quenching-tower stack. This requires a safe working platform. Before the coke car is driven in, the sampler is fitted in the center of the stack, its inlet bend pointing vertically downward. Sampling is completed when the car leaves the tower. To increase

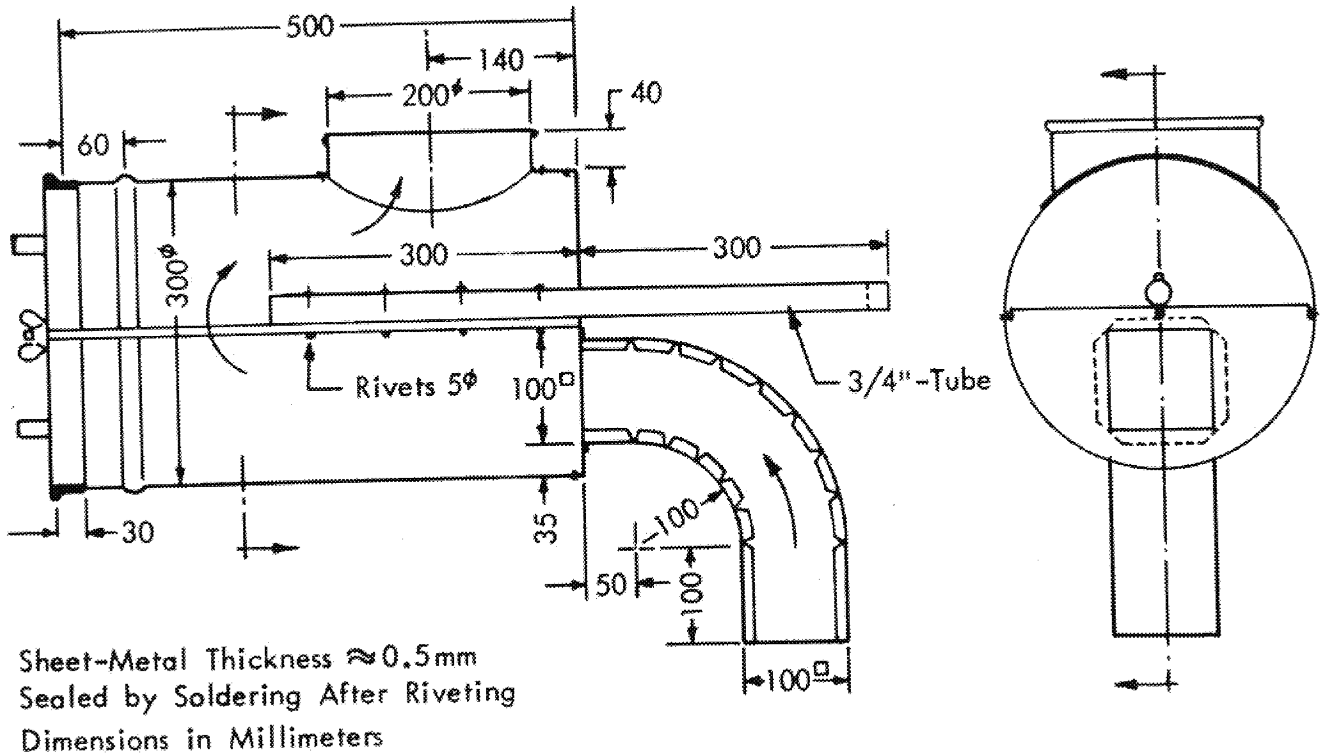


Figure 18. VDI-2303 sampling device.5/

accuracy, the sampler should be left at the sampling point during the quenching of several batches. It proved best to sample five quenching batches at a time.

After sampling, the lid is removed and the condensate transferred from the sampler to a container. Dust adhering to the walls is flushed with water and joined to the condensate. The content of the container is filtered through a previously weighed pleated filter. The filter with the dust is dried in a drying cabinet at approximately 105°C and weighed after cooling to room temperature.

Dust emission in grams per ton of coke can be approximately calculated for this measuring procedure from the following formula:

$$a = \frac{b \cdot c}{d \cdot e \cdot f}$$

where a = dust emission, g/Mg of coke

b = collected dust quantity, g

c = cross-section of quench tower (at sampling location), m^2

d = cross-section of sampler inlet pipe, m^2

e = number of quenching batches measured

f = weight of a coke batch, Mg[5/]

Inaccuracies in the results of tests may occur in two ways. Even though the system is designed to create a minimum of flow resistance, there will be some pressure drop across the device. The velocity through the sampler will be less than the velocity through the stack and all emissions estimates will be low.

The system will also be ineffective in the capture of fine particles. Neither the settling chamber nor a low resistance fabric will effectively capture particles less than ~ 10 μm in diameter. Therefore, the sampler will tend to capture only the larger particles. This is especially important in the analysis of the effectiveness of baffles. Since baffles are more effective in capturing large particles, this method will yield baffle efficiencies that are more representative of the capture of large particles, but not of the finer particles (i.e., biased on the high side).

Finally, the method assumes that emissions in the center of the stream are representative of emissions throughout the entire stream. It is improbable that this is the case.

4.1.3 Grease Plate Sampling

Several early tests were performed on quench towers using a greased plate technique. This method generally utilized a flat stainless steel plate coated with silicone grease. The plate was suspended horizontally in the stack for single or multiple quenches. The silicone grease is then removed with a solvent. The solvent is evaporated and the residue weighed. Total emissions are then obtained by the formula:

$$E = \left(r\right)\left(\frac{A}{a}\right)\left(\frac{1}{n}\right)$$

where E = emissions, g/quench

r = residue, g

A = area of stack, m^2

a = area of greased plate, m^2

n = number of quenches sampled

Results from greased plate tests are of little value. The technique is totally ineffective in capturing small particles. Again, it is impossible to determine whether the samples collected are representative. Finally, a significant quantity of particulate emissions leave the stack suspended or dissolved in water droplets. It is quesionable whether these droplets would adhere completely to the greased plate.

4.1.4 Grab Samples

Only one set of tests examined during the study were conducted using a grab sampling technique. Both gaseous and particulate concentrations were determined by sampling with a 1-ml syringe (this unusual technique is described further later in this report).

These tests gathered a total of four 1-ml samples from the air emissions stream during each quench. Velocities in the stack were determined and emissions calculated by relating the concentrations and stack velocity.

Results from any such analysis are highly suspect. First, it is questionable that with such a small sample the captured emissions are representative of the emissions stream. Second, the use of such a small capture mechanism will probably bias particulate results toward smaller particles. Finally, the method presumably was not carried out with any attempt to sample isokinetically.

4.2 QUENCH TOWER TEST RESULTS

Several emissions tests have been conducted on wet quench operations. It appears that substantial testing has been conducted in both Great Britain and Germany. However, detailed test data and process information are not available for most of these tests. A limited number of tests have also been conducted in the United States and Canada. Extensive efforts by MRI have been directed toward obtaining all possible data on these tests.

The following paragraphs describe the results of both foreign and domestic testing. Each test description will include when available: (a) process description; (b) sampling methodology; (c) emissions stream characteristics; (d) particulate emissions results; and (e) organic emissions results.

4.2.1 Foreign Test Results

Based upon our limited literature search, it is apparent that a significant number of tests have been conducted on emissions from wet quenching processes in Great Britain, Germany, and Eastern Europe. Because of the limited time frame and scope of this study, only those data readily available through the literature and by contacts with U.S. representatives of German corporations were obtained for inclusion in the study. Information from these sources is presented in the following sections.

4.2.1.1 Margam Works of the Steel Company of Wales, Ltd.[37/] - The earliest emissions data located during the study were obtained by Harris et al., from the Margam Works around 1960. The primary purpose of the tests was to determine the effectiveness of a baffling system in eliminating particulate emissions.

Process description--The Margam quench tower is an open-ended brick structure with an 18.3 by 6.1 m cross-section and 19 m high, reinforced internally by three sets of four tiebeams. A total of eight nonclogging sprays with total nominal capacity of about 1.7×10^4 liters/min (4,000 gal/min) are used to quench 11.8 Mg of coke in about 1 min. The tower is equipped with a grit arrestor consisting of a system of wedgewire grids and cleaning sprays situated above the main quenching sprays. The grids consist of 108 galvanized screens of 2 mm aperture arranged in two overlapping layers at 25 degrees from the horizontal. These are cleaned by 5.08-cm bore Sprayco sprays that have a nominal capacity of 2,720 liters/min (720 gal/min).

Coke is produced at Margam in ovens 13.6 m long by 3.8 m high by 45.7 cm wide that hold a coal charge of approximately 15.5 Mg. The charge is heated for a period of 18 to 20 hr and attains a temperature of about 1000°C. Generally 11.8 Mg of coke are produced per charge.

Sampling methodology--Emissions were sampled at two quench towers, one with and one without grit arrestors. Four types of sampling methods were considered: a suspended condenser, suction sampler, impaction on sticky surfaces, and downwind bucket sampling. Due to inaccuracies found in the condenser and the excessive number of quenches required to obtain sufficient sample using a suction sampler, the sticky surface method was chosen as the final method. However, some results were also obtained with the suction sampler. Both systems are described below.

Initially the sticky surface sampler consisted of an 11 cm by 11 cm filter paper covered with white silicone grease suspended at three points for varying times, and emissions patterns were determined. Since it was determined that almost all grit was emitted during the first 30 sec, 16 7 cm by 7 cm greased filter papers were suspended equally spaced, across the tower. Based on these results, a 0.30 m square aluminum plate coated with white silicone grease was placed at two points in the tower for the first 30 sec of the quench.

The grease and grit were scraped off the plate and dissolved in CCl_4. The solution was then filtered through a weighed Gooch crucible with glass wool mat. Particle size analysis was conducted on the collected grit.

The suction sampling equipment consisted of a heated 3.048 m stainless steel probe in which the captured stream was dried before entering a Fibergass thimble filter. The thimble was connected to two condensate catch bottles and an orifice meter by an 18.3 m rubber hose. The system had a maximum sampling rate of 0.228 m^3/min.

Emission stream characteristics--During the portion of the study in which the suction probe was examined, extensive temperature and velocity measurements were recorded. Both temperature and velocity were less in the tower with the arrestor than in the open tower. During a series of 23 tests in the tower with the grit arrestor, a maximum temperature of 65°C and a maximum velocity of 1.17 m/sec were recorded. A series of 22 quenches in the tower without arrestors produced a maximum temperature of 82°C and a maximum velocity of 1.57 m/sec. The lower velocity for the tests with the grit arrestor would be expected but the reason for the lower temperature is uncertain.

Particulate test results--Levels of particulate emissions were determined by suction sampling and by greased plate. Using the suction sampler, a total of 0.05 g was collected for each quench at the maximum rate of sampling. Based on an 0.228 m^3/min sampling rate and 30 sec sampling time, it appears that the Margam tower had a grain loading of about 460 mg/m^3. The total particulate emissions determined by each sampling method are presented in Table 2. Data are insufficient to determine whether the sample was collected isokinetically. The authors noted that the weights from the suction sampling may have included scale from the sampling probe. This would yield results with a high bias.

TABLE 2. MARGAM PARTICULATE EMISSIONS

Sampling method	With grit arrestor	Without grit arrestor
Suction		
kg/quench (lb/quench)	0.73 (0.94)	0.64 (1.40)
kg/Mg (lb/ton)	0.035 (0.07)	0.055 (0.11)
Greased plate		
kg/quench (lb/quench)	0.21 (0.46)	1.20 (2.64)
kg/Mg (lb/ton)	0.015 (0.03)	0.10 (0.20)

Greased plate samples were also analyzed for particle size. They found that with the grit arrestor that all the particles were below 500 m and that 20% were smaller than 66 μm. For the tower without grit arrestor, 82% were less than 500 μm and 3.1% were less than 66 μm (240 mesh). These data support the theory that baffling is effective in controlling large particles but much less effective in controlling fine particulate.

Organic emissions results--No data on organic emissions were given.

4.2.1.2 Bairds and Scottish Steel, Ltd., Gartsherrie Works[38/] - Several tests were conducted at the Gartsherrie Works to determine the effectiveness of different types of baffling arrangements in eliminating both particulate and droplet emissions from a quench tower.

Process description--The Bairds coking plant had 35 Becker ovens served by one quench tower. The rectangular tower was 13.7 m long by 5.2 m wide by 17.1 m high. The tower had arched openings at both ends, and was divided lengthwise into three bays of about equal size.

Baffle location and material were varied during the program to evaluate the effectiveness of each combination. The wooden baffles were comprised of two layers of 7.62 by 1.27 cm creosoted softwood louvres inclined at 70 degrees to the horizontal. Asbestos eliminators were constructed from one cycle high corrugations of "Big Six" asbestos cement sheeting set 4.45 cm center to center. The portion of the asbestos eliminators is depicted in Figure 19. The eliminators were also tested at two levels, one 1.83 m below the parapet, and one 2.13 m above the sprays. The baffle system did not have spray cleaners.

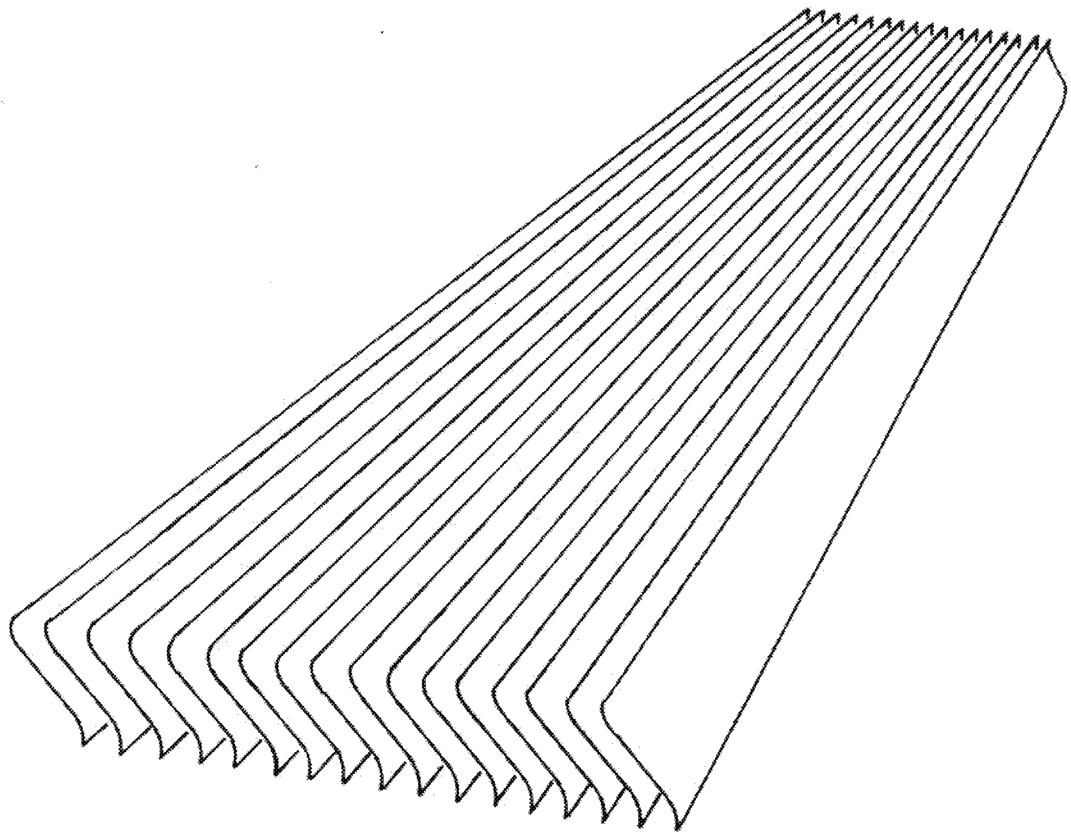


Figure 19. Asbestos cement eliminator fabricated from one cycle high corrugations cut from "big-six" sheeting.

Sampling methodology--The tests at Bairds were conducted using a suction sampler consisting of a 3.81 cm cyclone for separation and a calibrated inlet nozzle (no final filter was used after the cyclone). The system sampled emissions under approximately isokinetic conditions. The grit and droplets captured by the cyclone were collected in an 80 cc hopper.

Each of the three bays was divided into nine equal sections. One survey consisted of one sample from the center of each of the 27 sections. Each sample was taken for the first minute of the quench and each sample came from a different quench.

Total water captured was determined by weighing the cyclone hopper before and after the test. Total particulate were determined by evaporating all water, and then, by weighing the hopper.

Emissions stream characteristics--During the emissions tests at Bairds, extensive measurements were made of velocity, temperature and water carryover. Velocities were measured in each of the three bays using a pitot tube, modified to avoid water blockage. In each bay the velocity increased rapidly for the first 15 to 30 sec and then, gradually decreased. In the front bay the maximum velocity ranged from 2.1 to 5.2 m/sec. The middle bay ranged at a maximum from 3.7 to 5.5 m/sec, and the back bay, from 2.1 to 5.5 m/sec. Velocities of 0.91 to 1.5 m/sec were measured for at least 4 min after the start of the quench. This is about 2.5 min after the water is turned off.

Temperatures also increased rapidly for the first 30 sec, and then decreased to ambient over a 1- to 3-min period. Maximum temperatures ranged from 45 to 95°C (113 to 203°F) when ambient temperatures were in the 10 to 20°C range. It should be noted that temperatures were higher in some of the baffled systems than in the open tower. Also, both velocity and temperature decreased more rapidly in the open tower than in the baffled towers.

Total droplet emissions were also measured during the tests. For an open tower, the emissions ranged from 205 to 227 kg/quench. Data on water usage are not presented. Hence, it is not possible to determine the percentage of water carried over, per quench. Wooden baffles, at the lower level in the tower, reduced carryover to 145 kg/quench, and low asbestos eliminators reduced the quantity to 114 kg/quench.

Particulate emissions results--The particulate emissions tests at Bairds were conducted in two phases. The first phase tested the open tower and the wooden eliminators in the high position. At this time, coking operations were normal with coke being heated to 1200°C with a 19-1/2 hr coking time. The particulate emissions were 6.95 kg (15.3 lb) per quench for the open tower, and 3.5 kg (7.7 lb) per quench for the baffled tower, yielding an efficiency of about 50%. Particle size was also determined for these tests. The data are presented in Table 3.

TABLE 3. SIZE ANALYSIS OF GRIT[39/]

Size grade (microns)	Weight percent in size grade			
	Deposits[a/] in tower	Grit collected by sampling		
		No eliminators[b/]		Timber eliminators
Above 599	24.6	10.3	9.4	5.6
599-422	15.4	15.9	16.9	11.8
422-295	13.6	18.5	16.9	16.0
295-211	11.9	16.2	15.1	17.4
211-152	9.6	11.4	10.8	13.1
152-104	7.2	8.6	8.1	10.0
104-76	5.2	5.7	6.0	6.8
76-53	3.9	5.2	4.9	5.7
Below 53	8.6	8.2	11.9	13.6

a/ Size analysis of grit collected from the tower walls. The authors indicate these data suggest that some particles are broken upon entering the cyclone.

b/ Original reference gave two sets of values under the heading of "No Eliminators," but did not identify this meaning.

During the second phase of testing, the coke was heated to a temperature of 1100°C with a coking time of 35-1/2 hr. This change made a significant difference in total emissions. During this phase the open tower had emissions of only 1.39 kg (3.06 lb) per quench, an 80% reduction from the earlier tests. Another difference between the two tests was the method of quench. During the earlier phase, the water was turned on before the car entered the tower, and coke was quenched as the car moved into the tower. During the latter phase, the car entered the tower, and then the water was started.

These tests were used to determine the effectiveness of both timber and asbestos baffles at high and low heights. The resultant emissions and calculated efficiencies are presented below.

	Emissions kg per quench	Efficiency (%)
Timber baffles - High	0.51	63
Timber baffles - Low	1.41	18
Asbestos baffles - High	1.09	22
Asbestos baffles - Low	1.26	10

It is apparent that the timber baffles placed high in the stack were by far the most effective.

If we assume a minimum of 9.1 Mg of coke were produced per oven, a conservatively high estimate for total emissions are 0.765 g/kg (1.53 lb/ton) of coke for an uncontrolled tower and 0.38 g/kg (0.77 lb/ton) of coke for a baffled tower under normal operating conditions.

Organic emissions results--No data were collected on organic emissions.

4.2.1.3 United Nations Quench Data - Data on quench tower emissions from several European countries were compiled in a UN report.[40] However, no information on process conditions or test methodology was reported. The results from Poland, the United Kingdom, Czechoslovakia, and the USSR are given below.

Poland--Results were reported from testing at a coke plant which used wastewaters as makeup. The hydrocarbon portion of these quench tower emissions included:

Phenol	0.158 kg/Mg
Naphthalene	0.028 kg/Mg
Hydrorganic acid	0.0095 kg/Mg
Tar compounds	0.010 kg/Mg

The authors assumed that 50% of the coke in Poland was quenched with wastewater as makeup. Based on that assumption, the average emission rates for various pollutants from quenching processes were found to be:

Coke dust	0.143 kg/Mg
Coal dust	0.037 kg/Mg
Crude gas*	0.017 kg/Mg
Hydrocarbons (heavy)	0.098 kg/ton
Noxious gases	0.100 kg/Mg
Inorganic anions	0.100 kg/Mg
Total	0.490 kg/Mg

* "Crude gas" was undefined in Reference 40.

These data are based on analysis of condensates emitted from towers and direct measurement and mass balances to determine total emissions.

United Kingdom--Estimates of particulate emissions ("grit") and moisture emissions were developed for a coke plant producing 0.9×10^6 Mg of coke per year. Without grit arrestors, 225 kg/day of grit and 5 Mg/day of moisture are emitted. These are translated to emissions in kilograms per megagram of coke below.

	Grit	Moisture
Without arrestors	0.09 kg/Mg	1.82 kg/Mg
With arrestors	0.018-0.028 kg/Mg	0.18 kg/Mg

It appears that the arrestors are 70 to 80% efficient in controlling particles and about 90% efficient in controlling droplets. The report goes on to say that the particulate range in size from 7 to 100 μm with the largest fraction generally lying in the 8- to 80- μm range.

Czechoslovakia-- Dust emissions of 2 Mg/day were reported for a plant producing 2×10^6 Mg coke per year. This is a rate of 0.36 kg of dust per megagram of coke.

USSR--For a coke plant charging 100,000 Mg/day of coal, the following organic emissions are given: phenol - 0.240 Mg/day and cyanide compounds - 0.001 Mg/day.

4.2.1.4 Vaclav Masek, Czechoslovakia - Based upon available literature, it appears that an extensive amount of research has been conducted by V. Masek of Czechoslovakia. Most of his testing has utilized the sampling method suggested by the German VDI-Guidelines 2303. The method is described in detail in a previous section of this report. At present, translations of only two of Masek's studies are available to MRI. The results from these studies are presented below.

One of the two reports included tests conducted to determine the effects of various type baffle systems (see Figure 20) on particulate emissions from coke quench towers. Each of the systems was tested at 60, 70, and 80 degrees slopes from the horizontal. In the tower with no control, average emissions were 259.69 g of dust per megagram of coke (0.52 lb/ton coke). With baffles of Type b with a 60 degree slope (see Figure 20), emissions were 75 g/Mg (0.15 lb/ton). This system was the most efficient of the 12 possibilities. Particle size distribution for the total particulate for each of the baffle systems is given in Table 4. It appears that the baffles are more effective in collecting large particles, but not significantly so.[41] Again however, the test method probably does not effectively capture the fine particles.

The particulate were also analyzed for benzopyrene. It is significant that much higher levels of benzopyrene are present in the respirable dust and the grit between 5 and 200 μm than in the larger particulate. Calculations indicate that total benzopyrene content is 23.85 μg/g of particulate for a tower without baffles. This amounts to about 6.2 mg of benzopyrene per megagram of coke produced. With the 60 degrees Type b baffles, the benzopyrene content was 27.0 μg/g or 2.0 mg of benopyrene per megagram of coke produced. The benzopyrene contents by particle size for several types of baffles are shown in Table 5.[41]

The second study by Masek measured the mass particulate emissions and the corrosive nature of these emissions from a pressurized* and nonpressurized quench tower. The paper indicated that the particulate emitted measured 89.52 mg/liter/Mg coke for a pressurized tower and 327.56 mg/liter/Mg coke for a nonpressurized tower. The units used to express the emissions (milligrams per liters per megagrams) were not clear in the translated article and were not defined. At an earlier point in the paper, Masek indicated that total particulate emitted is about 500 g/Mg of coke (1.0 lb/ton).[42]

During the testing, the particulate was analyzed for 3,4-benzopyrene content. For the pressurized tower, 12 μg/g were emitted and for the nonpressurized tower benzopyrene emissions total 20 μg/g of particulate.

The particle size of emissions captured in the sampling train are presented below.

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* The translator of the article indicated that a "pressurized tower" referred to use of spray water at higher than normal pressure (i.e., 6 atm).

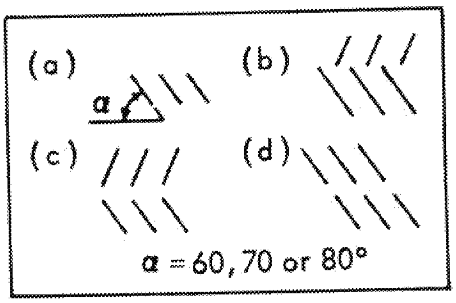

Figure 20. Different types of baffles.

TABLE 4. AVERAGE PARTICLE SIZE DISTRIBUTION OF WET QUENCH TOWER EMISSIONS

Type and slope of baffles		Number of quenches	Particle size distribution, in weight (%) 0 to 0.005 mm	0.005 to 0.1 mm	0.1 to 0.2 mm	0.2 to 0.3 mm	0.3 to 0.4 mm	0.4 to 0.5 mm
Without baffles		20	2.55	21.25	25.82	27.85	20.30	2.23
A	60°	10	1.85	26.55	28.65	23.90	17.30	1.75
A	70°	9	1.70	21.20	26.60	24.70	23.40	2.40
A	80°	10	2.95	30.90	30.90	21.60	12.55	1.10
B	60°	10	1.15	22.45	31 95	27.05	15.55	1.85
B	70°	10	1.45	19.40	29.75	27.70	19.65	2.05
B	80°	10	1.35	23.65	29.35	25.50	18.30	1.85
C	60°	10	1.45	23.25	32.50	23.85	17.15	1.80
C	70°	10	1.35	21.90	28.90	28.65	17.30	1.90
C	80°	9	3.65	27.60	26.55	24.80	15.75	1.65
D	60°	10	2.45	26.05	32.20	26.15	11.95	1.20
D	70°	10	2.20	23.00	24.80	32.00	16.30	1.70
D	80°	8	3.30	29.85	23.40	29.25	12.95	1.25

TABLE 5. 3,4-BENZOPYRENE CONTENT IN EMITTED DUST

Type and slope of baffles		3,4 Benzopyrene content in $\mu g/g$				
		0 to 0.005 mm	0.005 to 0.1 mm	0.1 to 0.2 mm	0.2 to 0.3 mm	0.3 to 0.5 mm
Without baffles		56	47	20	18	10
A	60°	45	38	24	15	12
B	60°	68	60	26	10	10
B	70°	91	79	21	14	10
C	60°	62	40	30	30	13
C	70°	37	35	18	14	9
C	80°	45	40	15	15	8
D	60°	58	40	15	12	10

Size distribution %(w)	Pressurized	Nonpressurized
0.000 - 0.005 mm	1.15	1.85
0.005 - 0.1 mm	21.20	22.40
0.1 - 0.2 mm	24.30	25.10
0.2 - 0.3 mm	26.45	24.52
0.3 - 0.4 mm	19.85	20.24
0.4 - 0.5 mm	7.05	5.89

Data on particulate measurements and tower parameters are too limited to be of value. However, particle size data and benzopyrene content are of interest.

4.2.1.5 German Test Data - Emissions data for several German quench towers were supplied to the EPA project officer by various German concerns. These data are presented in Table 6.

Process description--No information is available on the dimensions of the towers for which data are presented in Table 6. However, the control measure associated with each tower is described in the table. Each of these towers uses water recirculation with makeup water supplied from clean mill water.

Sample methodology--All tests were conducted under the guidelines suggested by VDI-2303 (see Section 4.1.2).

Emissions stream characteristics--No data were presented on velocity, temperature, or moisture content of the emissions streams.

Particulate emissions--Based on the data presented in Table 6, it is reasonable to assume that an average emission rate is about 200 to 250 g/Mg (0.40 to 0.50 lb/ton) for German quench towers. It should be noted that these measurements using VDI-2303 account for the nonsoluble particulate only. The dissolved solids from the entrained water droplets are not measured.

Four basic control options described in the table are (a) spraying during the pushing stage, (b) baffles, (c) backsprays in the plume, probably above the main spray system, and (d) combinations of backsprays and baffles. Based on these data, spraying during pushing reduces emissions from quenching by about 50%. This should be expected since most emissions occur early in the quench, and some of these early emissions would be released at the push. Baffling systems appear to be particularly effective in removing particulate emissions. The seven systems with baffles only that are shown in Table 6 have efficiencies ranging from 81 to 95% with most being in the 85 to 90% range. Efficiencies for backsprays alone ranged from 40 to 75%.

4.2.2 Domestic Data

Emissions data from domestic quench towers are not as widespread as data from foreign towers. However, associated design data and process descriptions

TABLE 6. GERMAN QUENCH TOWER DATA

Installation	Emission w/o Control (g/Mg of coke)	Control measure	Controlled emissions (g/Mg of coke)
Jacobi Ost[a]	260	Spray during pushing	120
	260	Spray during push and 30 degree slope Otto baffles	70
	260	Spray during push and 30 degree slope Otto baffles and spray in plume	50
Kaiserstuhl A/B[a]	400	Nathaus KG baffles	60
Minister Stein[a]	250	Nauthaus KG baffles	40
Koenigsborn[b]	200	Backspray	160
Grimberg[b]	300	Backspray	50
Minister Stein[b]	160-200	Backspray	40-100
Erin[b]	130-200	Backspray	30-120
Hansa[b]	60-120	Backspray	-
Friedrich Heinrich[b]	80	Backspray	30
Pforzheim[b]	-	Backsprays and multiple baffles	20
Koenigsborn 3/4[c]	200-250	Fa. Carl Still's quenching stack baffles	34-35
Minister Stein No. 1[c]	200-250	Fa. Carl Still's quenching stack baffles	34-42
Minister Stein No. 2[c]	200-250	Fa. Carl Still's quenching stack baffles	15
Jacobi No. 1[c]	200-250	Fa. Carl Still's quenching stack baffles	14.3-16.7
Osterfeld[c]	798	Two rows Fa. Carl Still's quenching stack baffles	37

a/ Data contained in letter from Dr. C. Otto, of McKee-Otto Engineers, to Mr. Naum Georgieff of EPA, dated July 1977.

b/ Data supplied by Rurhkohl to Dr. C. Otto. Transmitted to Mr. Naum Georgieff of EPA in letter dated July 1977.

c/ Data supplied in a letter from Mr. R. Weber, of Carl Still Corporation, to Mr. Naum Georgieff of EPA, dated June 8, 1977.

are more complete. Extensive testing has been conducted at DOFASCO in Ontario, Canada, and at U.S. Steel's Lorain, Ohio, plant. Some additional testing has been done at Bethlehem's Tonawanda and Lackawana plants, U.S. Steel Clairton, Kaiser Steel, Armco Houston Works, Donner Hanna Coke Corporation, Shenango, Inc., and Inland East Chicago. Data have been requested but have not yet been received for the last three plants. The data that have been obtained are described in the following sections.

4.2.2.1 United States Steel, Clairton, Pennsylvania[43/] - The earliest reported emissions tests in the United States were conducted by R. W. Fullerton of U.S. Steel in 1967. These tests were designed to determine the effectiveness of baffles in eliminating emissions from coke quench towers.

Process description--The tower used for the Clairton study is a 4.6 by 4.6 by 30.5 m high wooden structure. The typical quench utilizes 1.5×10^4 liters of water over a 2-min period to quench about 11.8 Mg of coke. The water is circulated to extinction with about 2.5×10^3 liters/quench lost by evaporation and carryover. No information was given as to the source of makeup water.

In determining the best type of baffling, four arrangements were tried: (a) a single tier of baffles inclined 70 degrees from the horizontal; (b) a single tier inclined 45 degrees from the horizontal; (c) a double tier of baffles inclined 70 degrees; and (d) a double tier of 45 degree baffles. It was found that the double tiers provided excessive flow resistance and so were not satisfactory. The 45 degrees baffles provided greater reduction than the 70 degrees baffles, and hence, were chosen for installation.

The final baffles were 1.9 by 15 cm sections of redwood. These were installed 4.1 cm apart. The baffling was provided with a spray system consisting of a 10 cm stainless steel pipe manifold with 16 full-cone nozzles.

Sampling methodology--After examining several methods for sampling particulates, the greased plate method was chosen. The plate was made of a 9.3 cm^2 of 16-gauge stainless steel. It was coated with a temperature and moisture resistant grease, and was inserted in the tower during the quench. Velocity was determined by Pitot-tube traverses, and temperatures were measured by a thermocouple.

Emissions stream characteristics--Velocity and temperature measurements were made at the center of each of 16 equal-area zones in the tower cross-section. The velocity reached a maximum of 11 m/sec during the first 10 sec of the quench and then gradually decreased to 7.3 m/sec by the end of the 2-min quench. The temperature reached a maximum of 70°C after 10 sec, and then receded to 54°C by the end of the quench. No data were given on moisture content.

Particulate emissions data--The average particulate emissions in an open tower were about 13.2 kg/quench or 0.25 kg/Mg coke (6 lb/quench or 0.5 lb/ton coke) with almost 90% of these emissions occurring during the first minute of the quench. A screen analysis of the captured emissions is presented below.

Screen mesh size	Particle size (μm)	Percent above size
6	> 1,600	0
16	~1,200	1
30	~ 600	10
50	~ 300	45
100	150	84
200	75	97
-200	< 75	3

After installation of baffling, emissions were reduced to about 1.65 kg/quench or 0.03 kg/Mg coke (0.75 lb/quench or 0.06 lb/ton coke). This represents an emissions reduction of about 85 to 90%.

Organic emissions data--No organic data are available.

4.2.2.2 Kaiser Steel Corporation, Fontana, California[44-46] - The South Coast Air Quality Management District, San Bernadino Zone (previously San Bernadino County Air Pollution Control District) conducted a series of three tests on Quench Tower No. 3 at Kaiser Steel Corporation. The first was performed in January 1972, and the last in February 1977.

Process description--The Quench Tower No. 3 at Kaiser tapers above the spray system to a 5.2 m square duct with a baffling system near the top of the tower. Data are insufficient to determine size of the tower at the base or stack height. Each quench at Tower No. 3 handles about 8.2 Mg of coke over a 3-min period. An average of six to nine quenches is conducted each hour.

Sampling methodology--Standard Method 5 sampling equipment was utilized in these tests. However, in the first test the filter was upstream of the impingers, but for the later tests in 1977 the sampler was changed such that the filter was downstream of the impingers. The tests were conducted over the top of the tower at a single point in the plume. The sampling rate was varied at three times during a quench based upon velocity profiles previously obtained.

Emission stream characteristics--Limited data on stream characteristics are available from the three reports. The 1972 report gave a stack temperature of 80° C,[12] while the 1977 results indicate a stack temperature of 105° C.[14] An analysis of moisture and gas density was reported only in the 1972 report. A moisture content of 38.95% was reported.

Specific data on stack flows were not reported. However, velocities can be calculated based on a cross-sectional area of 26.9 m^2. The 1972 report indicated a gas flow of 8,487.3 Nm^3 at 80°C which yields a velocity of about 6.4 m/sec. Data from the other tests are insufficient to determine an exact flowrate. However, if an average moisture content of 30 to 50% is assumed, the data from 1977 yield a velocity of 4.0 to 5.5 m/sec.

Particulate emissions results--Particulate emissions were measured during each of the three tests. In the initial test an average particulate loading of 84.7 mg/Nm^3 was measured during the quench period. This resulted in a particulate discharge of 13.67 kg/hr (30.08 lb/hr) or 0.255 kg/Mg (0.51 lb/ton) of coke quenched. This was an average for nine quenches.[44]

The 1975 tests resulted in an average loading of 89.2 mg/Nm^3 (0.039 gr/dscf). This translates to a discharge of 9.23 kg (20.3 lb) particulate per hour or 0.16 kg/Mg (0.32 lb/ton) of coke quenched. It was noted at this time that three out of four baffles were severely eroded and new baffles were to be installed.[45]

The 1977 test was scheduled after the new baffles were installed. The particulate loading was measured as 43.0 mg/Nm^3 (0.0188 gr/scf). The resultant discharge is 9.15 kg/hr (20.12 lb/hr) or 0.055 kg/Mg coke (0.11 lb/ton coke). The lab results for this test may be of some interest. The breakdown of particulate catch is as follows:[46]

	% of Particulate Catch
Impingers and accessories	3.7%
Filter (following the impingers)	2.0%
T.D.S. in impingers	94.3%

This seems to indicate that significant amounts of material are emitted as dissolved solids in water droplets, or are dissolved during the sampling process.

Organic emissions results--During the 1972 tests, grab samples of the emissions stream were taken for phenolic compounds. The two grab samples showed an average phenol concentration of 14 ppm. The quench tower sump water was also analyzed for phenolic compounds. The results showed an average of 536 ppm.

4.2.2.3 Bethlehem Steel Company, Tonawanda, New York[47] - In July and August of 1973, the State of New York conducted tests on the "B" Quench Tower at Bethlehem's Tonawanda plant. Particulate, BaP, and hydrocarbon emissions were measured.

Process description--No data were presented which described either the quench tower or the process parameters. The report does indicate that quenching time varies from 1.5 min to 3 min. It appears from comments and diagrams that the tower is open (i.e., has no baffles).

Sampling methodology--For particulate sampling, the stack was divided into nine equal cross-sectional areas. The average velocity was determined for the first and second minutes of the quench cycle, and these were used as sampling rates for a number of quench cycles using standard New York State sampling methods, similar to the EPA Method 5 train.

BaP sampling was conducted with methods similar to those used for particulate. However, the sampling nozzle was reduced to 0.3175 cm, the sampling was limited to only three central points, and a benzene wash was used on the sampling train.

Emissions stream characteristics--Nine different locations were sampled within the tower with 17 to 24 quenches sampled at each location. The average stack temperature for each location was 65° C. The average stack velocity for each point ranged from 5.2 to 8.32 m/sec with the center velocity at 6.1 m/sec. No data were presented on moisture content.

Particulate emissions data--Particulate measurements were also taken at each of the nine points. The average particulate loading was found to be 252 mg/Nm^3 (0.11 gr/scf). Based on an average of 8.5 quenches per hour, an emissions rate of 48.4 kg/hr (106.5 lb/hr) was developed by the authors. This results in an average particulate emission of 5.68 kg (12.5 lb) per quench.

No data on the amount of coke per quench were reported. However, Battery No. 6 is an 11-ft Wilputte oven. Based on data from similar ovens, it is assumed that each push results in about 10.9 to 11.8 Mg of coke. Thus, an emission factor of 0.5 kg particulate per megagram of coke quenched (1.00 lb/ton) is estimated.

The report also noted that analysis of the test results indicated that 90% of the sample was collected in the cyclone and probe. Hence, most of the emissions are probably large particles. The authors indicated that simple control equipment would probably eliminate the quench tower particulate problem.

Organic emissions results--Quench tower emissions were tested for BaP, phenols, and hydrocarbons measured as decane. Total BaP analyses were never completed for the tests. However, particulate BaP results are available for two sets of tests, one in which the particulate samples were analyzed for BaP after particulate analysis was completed and another separate set of tests for BaP. The particulate samples were taken over six locations in the tower as explained previously. If we assume these locations are representative, an emission factor in the range of 0.163×10^{-3} to 0.326×10^{-3} kg of BaP/Mg of coke can be calculated.

Samples were taken at the three sampling locations in the center section of the tower for BaP only. The resultant emissions ranged from 0.092×10^{-3} to 0.171×10^{-3} kg of BaP/Mg of coke for the center section only. If we assume that the center section accounts for one third of the total emissions (an assumption which appears reasonable based on particulate data) total BaP emissions from the quench tower range from 0.276×10^{-3} to 0.511×10^{-3} kg/Mg of coke. Thus, the two sets of results yield comparable results, but represent only particulate BaP.

A total of 94 quenches were sampled to determine total hydrocarbon emissions. Total hydrocarbon emissions were determined to be 6.59 kg/hr or 0.085 kg/Mg (14.5 lb/hr or 0.17 lb/ton estimated) with about 50% of the emissions reported on the north end of the tower. Average phenol emissions were reported to be 0.26 kg/hr or 0.003 kg/Mg (0.57 lb/hr or 0.006 lb/ton), again, with 50% of the emissions exiting the north end of the tower.

4.2.2.4 Bethlehem Steel Corporation, Lackawanna, New York[48/] - During April and May 1974, the State of New York Region 9 test team tested particulate, BaP, phenol, and total hydrocarbon at Bethlehem's North Quench Tower. This tower serves coke oven Battery No. 9 and occasionally Battery No. 7.

Process description--Information on the process presented is limited. The north quench tower serves the No. 9 coke battery, which is made of 6.1 m (241 in.) Wilputte ovens. It is estimated that these ovens will discharge about 22.1 Mg (24.3 tons) of coke per push. Each quench lasts approximately 3 min, and about 4.3 batches of coke are quenched each hour.

Water at the north quench tower was recycled to extinction. Makeup water was a combination of effluent from the larry car scrubber and fresh water.

The tower does have a baffling system, located immediately above the water sprays, for emissions control. The baffles are described as wooden grid-type louvres with backsprays to provide cleaning. The tower reduces from about 18 m in length at grade, to a 5.10 m square stack above the baffling. Further design data have been requested but are not available at this time.

Test methodology--The stack was divided into nine equal area sections. The sampling was conducted at eight of the nine points using a modified Method 5 train. Generally, 18 quenches were sampled at each point. After determining particulate weight, the samples were examined for BaP content.

Emissions stream characteristics--Two complete test runs were conducted on the north quench tower. Results of the two runs showed a high degree of consistency. The stack temperature for the first run ranged from 55 to 66°C with an average of 61°C. The second run had a range of 58 to 63°C, again, with an average of 61°C.

The stack velocities for the two runs were 8.00 m/sec for the first run and 8.02 m/sec for the second run. In each case, the south section of the tower had the lowest velocity (7.436 m/sec and 7.272 m/sec, respectively) and the center section had the highest velocity.

Initial analysis of the impingers indicated that moisture levels in the stack were in the range of 50%. However, analysis of stack conditions led to the conclusion that the saturation point of the gas stream was only 20%. Thus, the report assumed that the gas stream was saturated and that the additional moisture was droplet carryover.

Particulate emissions results--The average concentration of particulate in the gas stream was 446.2 mg/Nm^3 (0.1950 gr/scf) for the first run, and 422.6 mg/Nm^3 (0.1837 gr/scf) for the second run. Loadings in the different test sections for the first run ranged from a high of 635.8 mg/Nm^3 (0.2779 gr/scf) in the south section, to 305.9 mg/Nm^3 (0.1337 gr/scf) in the middle section. During the second test, the south section, again, had the highest loading at 519.8 mg/Nm^3 (0.2272 gr/scf) with the middle section the lowest, at 302.9 mg/Nm^3 (0.1324 gr/scf).

Total particulate catch was calculated to be 46.3 kg/hr (102.31 lb/hr) for the first run, and 46.50 kg/hr (101.55 lb/hr) for the second run. This averaged to 46.33 kg/hr (101.93 lb/hr). Based on an average of 4.3 quenches per hour, and an average of 22.1 Mg (24.3 tons) per quench, an average emission rate for the two runs of 0.49 kg/Mg (0.98 lb/ton) was calculated. These emissions are for a partially offset baffled tower using makeup water from the larry car scrubber plus clean water.

Organic emissions results--Particulate emissions were analyzed for BaP content. In addition, gaseous phenols and hydrocarbons were measured.

Average BaP emissions for two runs were calculated to be 1.25×10^{-3} kg/hr or 1.32×10^{-5} kg/Mg coke (2.76×10^{-3} lb/hr or 2.64×10^{-5} lb/ton coke). This amounts to 0.0027% of the total particulate catch. It is of interest that in both tests the highest concentrations of BaP were found in the outside portions of the tower. This might be expected since the coke in the ends of the car is less completely coked than that in the middle.

The impinger train shown in Figure 21 was used to sample gaseous emissions. For phenols, 15 ml of 0.1 normal sodium hydroxide was used in the first three impingers with a dry fourth impinger. The hydrocarbon train had 20, 15, and 10 ml of trichloral trifloral ethane in the first three impingers. Single point sampling was used for each of three runs with a different point used for each run.

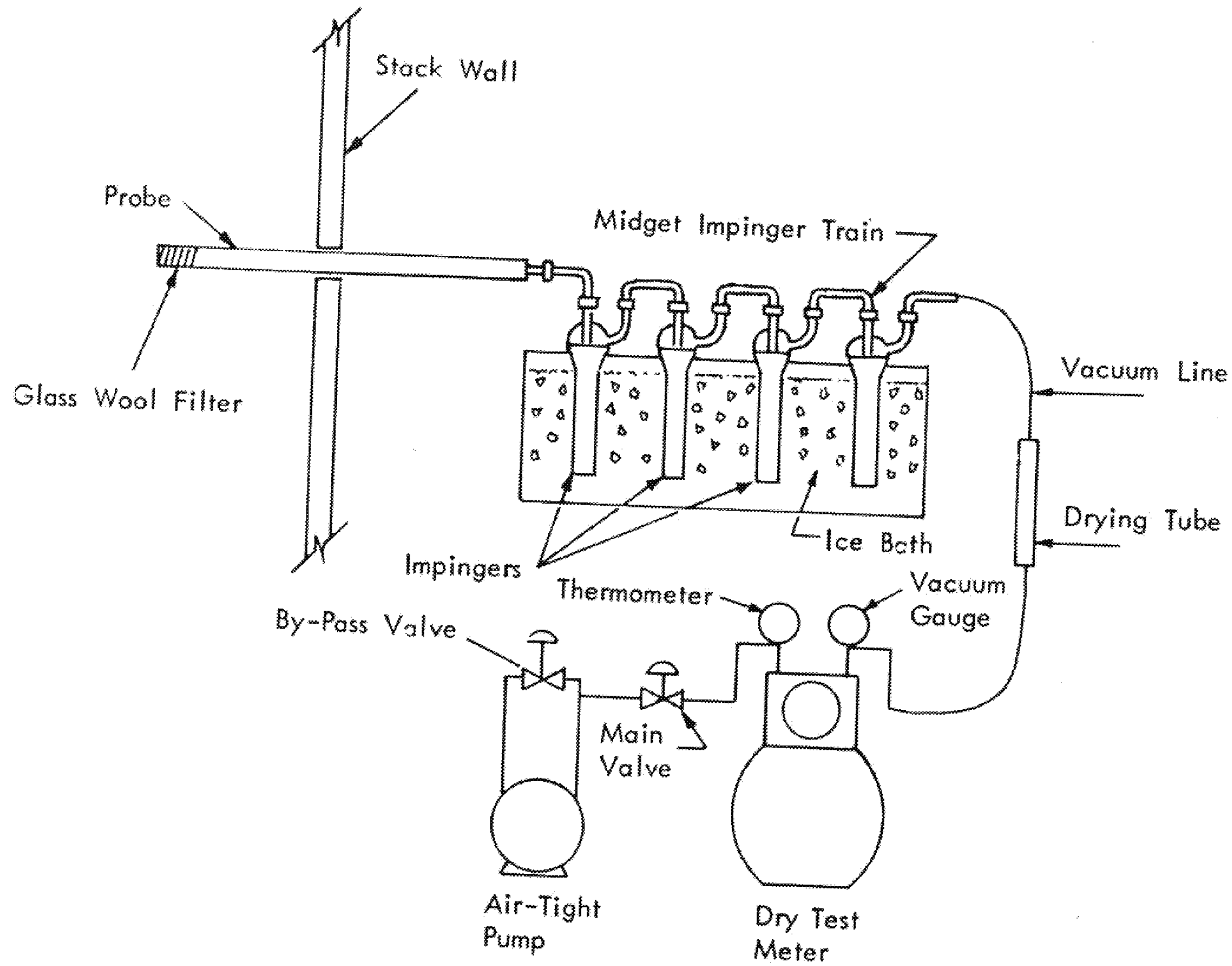

Figure 21. Gaseous sampling train.

Average phenol emissions were found to be 8.707 kg/hr or 0.093 kg/Mg coke (19.156 lb/hr or 0.186 lb/ton coke) with a range of 5.324 to 11.572 kg/hr or 0.066 to 0.122 kg/Mg coke (11.713 to 25.458 lb/hr or 0.112 to 0.244 lb/ton coke). The three hydrocarbon runs yielded an average emission rate of 0.798 kg/hr or 0.0084 kg/Mg coke (1.756 lb/hr or 0.0168 lb/ton) with one run having a hydrocarbon catch below detectable limits. Highest emissions on any run were found to be 1.423 kg/hr or 0.015 kg/Mg of coke (3.131 lb/hr or 0.030 lb/ton coke).

4.2.2.5 CF&I Steel Corporation[49/] - A series of tests was conducted to compare particulate and gaseous emissions from a quench tower using two water sources, an industrial-grade water and discarded water from the coke oven by-products plant.

Process description-- The test report presented little process information. However, based on comments in the report, it has been inferred that the tests were performed on CF&I's south tower, a rectangular tower without baffles. The tower is approximately 5.2 by 13.7 m internally and is 18 m high. Quenching time is set at 1 min 48 sec, and about 2.1×10^4 liters of water are used per quench with each quench consisting of about 13.75 Mg of coke.

Test methodology--Several samples were collected from various points in the emission stream using 1-ml syringes to determine both gaseous and particulate concentrations. Three to four syringes were filled during each quench, and four dirty water and four clean water quenches were sampled. Particulate concentration was determined with an instrument specified only as a Celesco Model 39D. Phenols and hydrocarbons were determined using a carbo wax 1540 column on a Carle Model 8000 portable gas chromatograph. Plume velocity was measured using a standard velocity probe.

Emission stream characteristics--The temperature measured in the plume was found to be 60°C during the "dirty" water quenches, and 40°C during the clean water quenches. The clean water passed once through and thus, was cooler than general quench water. The plume velocities were 7.01 and 7.53 m/sec for the "dirty" and clean quenches, respectively. It was noted that these velocities were only true for the center section of the tower and that downdrafts were present in both end sections.

Particulate emissions results--The particulate loading for the "dirty" quench ranged from 12 to 16 mg/m^3 (5.2×10^{-3} to 7×10^{-3} gr/ft^3). The clean water loading ranged from 8 to 12 mg/m^3 (3.5×10^{-3} to 5.2×10^{-3} gr/ft^3). If we assume that emissions from each quench last for 3 minutes and are emitted only from the center section at the rates suggested above, emission rates can be calculated. The cross-sectional area of the center section is 26.45 m^2. The emission rates from the "dirty" quenches range from 0.398 to 0.536 kg (0.875 to 1.18 lb) per quench. The clean water emission rates range from 0.287 to 0.427 kg (0.633 to 0.940 lb) per quench. Assuming 11.4 Mg of coke per quench, the emissions average 0.044 kg/Mg (0.088 lb/ton) for dirty water and 0.031

kg/Mg (0.062 lb/ton) for clean water. These results are questionable because of the very unusual sampling method (i.e., use of 1-ml syringes). On the average, this CF&I data show about a 25% reduction in emissions from the change to clean water. It should be noted that the assumption that the plume is only emitted from the center section is contrary to most observations, and may lead to an erroneously low emission rate.

Organic emissions results--Phenols were detected at levels ranging from 450 to 550 ppm in the "dirty" water plume. None was detected in the clean water plume. Total low vapor pressure hydrocarbons were found at 3,000-ppm levels in the "dirty" water plume and 600 ppm in the clean water plume.

4.2.2.6 Armco Houston Works[50/] - From September 5 through September 10, 1975, particulate tests were conducted on the quench tower at the Houston Works of Armco Steel.

Process description--The quench tower is a rectangular structure 5.2 by 14.2 m with a 20.7 m height. The tower is divided into three horizontal sections with the outside sections 4.78 m long and the middle section, 4.57 m long. The tower is supplied with a set of baffles located 1.75 m below the top of the tower. The baffle system consists of three rows of baffles inclined 45 degrees from the vertical in alternating directions. Based upon calculations and a total height through the baffles of 30.5 cm, it is probable that the baffles are constructed of 15.2 cm wooden louvres. The baffle system is equipped with backsprays.

During each quench a total of 11.8 Mg of coke are processed. Each quench lasts 3 min, and an average of 3.25 quenches are completed per hour. No data on water use were presented.

Sampling methodology--A series of four particulate tests was run using a standard EPA Method 5 train with a modified sampling sequence. The first test (PNA-1) was conducted at a single point near the center of the west tower section for a total of 30 quenches. For the second test (PNA-2) 24 points, a 3 by 4 grid in each of the west and central sections, were sampled. The third and fourth tests (GAS-3 and GAS-4) were sampled at a single point shown to have a high velocity.

Emissions stream characteristics--Stack temperature, stream velocity, and moisture content were determined for each of the four runs. For the four runs, temperature measurements were fairly constant, ranging from a minimum of 68°C to a maximum of 90°C with average temperatures in the 74 to 77°C range for the four runs.

Velocities varied significantly in the various runs, with location in the tower having a substantial effect on velocity. During the first runs with single point sampling, the velocity ranged from 2.5 to 3.75 m/sec with an average of 3.11 m/sec. During the second test when a traverse was used, velocities ranged from 0.64 to 6.58 m/sec, with an average of 3.23 m/sec. Finally, during the last tests, when the sampling point was chosen for high velocity, velocities ranged from 5.15 to 7.77 m/sec, with an average velocity of 6.58 m/sec.

Moisture content was high in all four tests ranging from 27% to 71% with an average of about 42%. These values were determined by saturation temperature (psychrometric tables) rather than condensate. However, the report indicated that the two values (saturation level and condensate) were generally in good agreement. This indicates a minimal amount of entrained water droplets.

Particulate emissions--The report indicated that particulate deposition in the probe and in the impingers was minimal. Hence, reported emissions consist only of the filter catch. Particulate loadings and total mass emissions are presented in Table 7.

TABLE 7. ARMCO PARTICULATE RESULTS

	Grain loading mg/Nm^3 (grains/dscf)	Emissions kg/Mg coke (lb/ton of coke)
PNA-1	98 (0.043)	0.135 (0.27)
PNA-2	105 (0.046)	0.14 (0.28)
GAS-3	135 (0.059)	0.18 (0.36)
GAS-4	144 (0.063)	0.195 (0.39)

Organic emissions data--No organic emissions were included in the sampling.

4.2.2.7 Dominion Foundries and Steel Ltd., Hamilton, Ontario[51/] - In August 1977, York Research Corporation conducted an extensive sampling program on the quench tower at DOFASCO's No. 2 coke plant in Hamilton. Tests were conducted under three sets of conditions: normal operations (water recycled to extinction); normal operations with baffle sprays operated during the quench; and quenching with water restricted to once-through bay water. Both particulate and organic emissions were sampled but the organic results have not been released.

Process description--The No. 2 coke plant has two batteries of 53 ovens and a single quench tower. The coking time is approximately 15.5 hr. About 10.9 Mg of coke are produced in each oven.

The coke is quenched in a rectangular wooden quench tower. The exact dimensions of the base of the tower are not given. Based on drawings, it is estimated that the tower is about 15 m long by 5.6 m wide with a total height of 16.5 m. The tower narrows on one end through the middle third of its high to reach a stack size of 11.3 m by 5.6 m.

Two rows of 2.5- by 15-cm wooden baffles are positioned 3.0 m from the top of the tower. The baffles are placed at 20-degree opposing angles. The baffling is equipped with backsprays.

The 10.9 Mg are quenched using two spray periods. The first spray period lasts 45 sec, followed by a 20-sec interval with no sprays and another 30-sec spray period. No data on amounts of water used or consumed were presented. However, the report indicated that normally water is recycled to extinction, with makeup consisting of fresh bay water.

Sampling methodology--Emissions testing at DOFASCO utilized a high volume Aerotherm sampling train. Sampling was conducted near the top of the tower, about 1 m above the baffles. The particulate system was fitted with an unheated cyclone with 50% cut size (D_{50}) of 10 μm to remove large particles and water droplets. The remaining gases were then drawn through a heated Spectrograph Type AE filter and impinger train, followed by the control module. A strip chart recorder and Hastings velocity meter were used in conjunction with the particulate sampling system to determine velocities. Preliminary velocity measurements allowed sampling during each quench at approximately isokinetic conditions by modifying the flow during three distinct portions of the quench. It is not clear from the text whether sampling was conducted at a single point with velocity profiles determined across the stack, or whether sampling was conducted at different points in the stack.

Emissions stream characteristics--Preliminary measurements were made to determine stack temperature and to profile the velocity with respect to both stack location and temporal variation through the quench. Temperatures were measured using both a potentiometric method and a strip chart recorder. Both methods measured temperatures in the 68 to 70°C range throughout the quench. Average stack temperature during actual testing was approximately 68°C.

Measurement of the velocity profiles indicated three distinct phases: (a) ramp up,* a sharply increasing flow from the time the car entered until the water was turned on (10 sec); (b) plateau, a relatively even velocity, with some decrease during the interim nonspray period, from the time the quench starts until the second quench ends (1.5 min); and (c) ramp down, a gradual decrease in velocity from the end of spraying until the car leaves the tower (~ 30 sec). The average velocity for each of the 17 tests ranged from 2.0 to 4.1 m/sec.

* Ramp up, plateau, ramp down are descriptive terms describing velocity patterns at various times in the quench.

Moisture content of the stream was measured for each of the tests, probably based on the amount of condensate in the impinger train. Moisture content on the 17 tests ranged from 25.1 to 51.0%, with an average of 37.9%. Based on the psychrometric chart and the temperature range of 65 to 71°C for each test, moisture content at saturation should be in the range of 21 to 29% by weight.

Particulate emissions results--As indicated above, emissions were determined at DOFASCO for three sets of conditions:

1. Normal operating procedure with water circulated to extinction and fresh bay water used for makeup.

2. Normal operation with the exception that baffle back-sprays were operated during quenching.

3. Quench water is fresh bay water used on a once-through basis (no recycle).

Data on grain loadings and emissions in kilograms per megagram and pounds per ton of coke for each of the 17 runs are presented in Table 8. These values represent total front and back half catch plus cyclone dissolved solids. The average emissions for each of the three types of operations are:

Normal - 0.238 kg/Mg coal charged;

Baffle sprays - 0.206 kg/Mg coal charged; and

Once through - 0.291 kg/Mg coal charged.

If we assume that 1 Mg of coal produces 0.6 Mg of coke the average emissions in kilograms per megagram of coke are 0.394, 0.342, and 0.485, respectively. As indicated by the data, the emissions from the once-through bay water are higher than those for recirculated water.

An approximate particle size distribution can be developed for the DOFASCO tests based on the location of capture within the train. The four primary areas of particulate capture are: (a) cyclone, including dissolved solids; (b) probe rinse; (c) filter; and (d) back half. The approximate size range for each area is:*

Cyclone	$> 10.2\ \mu m$
Probe	$3.0\text{-}10.2\ \mu m$
Filter	$0.3\text{-}3.0\ \mu m$
Back half	$< 0.3\ \mu m$

* It appears from the diagrams in the test report that the cyclone was on the front end of the probe.

TABLE 8. DOFASCO PARTICULATE EMISSIONS DATA

Quench Mode	Test No.	No. of Quenches	Particulate Loading mg/Nm^3	Emissions kg/Mg Coal
Normal (Water Recycle)	1	6	237.0	0.162
	1A	6	286.0	0.308
	2	6	238.6	0.262
	4	6	307.0	0.240
	5	6	214.8	0.220
	9	6	197.9	0.222
	10	6	296.3	0.196
	11	6	250.5	0.184
	12	6	263.3	0.346
Baffle Sprays	7	6	348.0	0.209
	8	6	218.0	0.202
Once-Through Bay Water	13	3	288.3	0.239
	14	3	569.7	0.298
	15	6	310.5	0.319
	16	6	226.3	0.206
	17	6	312.3	0.370
	18	6	288.1	0.312

The mean diameter of the cyclone particle catch was determined by Coulter analysis to be 64 μm. The size distribution for each of the tests is presented in Table 9. As can be seen from Table 9, all except six of the 17 quenches have extremely low quantities of large particles. In all except two of the cases (tests Nos. 1A and 13) much of the large particle catch is made up of dissolved solids. For tests 7 and 8, these emissions may be a result of the back spray system. Data from the other four tests give no indication of possible reason for the increase in dissolved solids.

Organic emissions results--Data from the organic tests at DOFASCO have not been released by the Ministry of Environment.

4.2.2.8 U.S. Steel - Lorain[52] - The most exhaustive examination of quench tower emissions has been conducted by York Research Corporation for the U.S. EPA. The studies have included an analysis of sampling problems associated with quenching operations and two different sets of quench tower tests for both organics and particulates. Complete results from the second set of tests are not yet available.

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TABLE 9. DOFASCO PARTICLE SIZE DATA

Quench Mode	Test No.	Cyclone (%)	Probe (%)	Filter (%)	Back Half (%)
Normal	1	3.9	36.6	17.0	42.5
	1A	24.0	35.2	5.6	35.2
	2	1.6	25.2	21.9	51.3
	4	5.4	30.3	19.8	44.5
	5	19.1	46.3	9.2	25.4
	9	6.1	39.0	10.1	44.8
	10	10.3	44.5	0.9	44.3
	11	5.1	48.3	18.2	28.4
	12	3.9	35.6	4.9	55.5
Back Sprays	7	14.3	47.2	4.1	34.3
	8	16.6	41.2	0.6	41.6
Once-Through Bay Water	13	14.0	44.2	11.4	30.4
	14	1.8	43.7	3.3	51.2
	15	2.0	22.3	1.3	74.4
	16	3.9	31.0	3.1	62.0
	17	3.3	41.4	4.0	51.3
	18	2.6	15.3	11.5	70.6

Process description--In examining the results of the Lorain test it is important to bear in mind that the site was chosen for its testing suitability rather than as a representative quench tower. Quench Tower No. 1 at Lorain is a circular brick structure which services G, H, and I batteries. These are all Koppers ovens, and, based on charging data presented in the report, the ovens yield 8.7 Mg of coke per push with about 0.9 Mg of that quantity being coke breeze.

After the coke is pushed from the oven, it is cooled by using a total of 2.6×10^4 to 3.4×10^4 liters of water over approximately a 2-min period. Make-up water at Lorain may be either clean river water or wastewater from the by-products plant.

The quench tower at Lorain is a circular brick structure with an inner diameter at the top of 5.28 m and a height of 36.6 m. The baffles, located in the lower part of the tower, are constructed of 5.1-cm by 25-cm wood and are inclined at approximately 45 degrees. Data on base size of the tower were not presented.

Sampling methodology--Sampling methodology for particulates was essentially the same as the procedure used at DOFASCO. Each test consisted of samples of three to five quenches at a single point in the stack with different tests being performed at different points. A series of four tests was conducted for organic emissions using the Hi-Volume Aerotherm train with a water-cooled adsorber trap filled with porous polymer between the filter and impingers. The analysis scheme consisted of a liquid chromatographic separation of the concentrated extracts from the train which were later characterized by infrared spectroscopy. In addition, a separate mass spectroscopy scan for polynulear aromatic hydrocarbons was performed.

Emissions stream characteristics--As was the case at DOFASCO, preliminary analyses were conducted to accurately determine velocity and temperature characteristics of the tower. A set of six thermocouples at various heights along the side of the stack were used to record stack temperatures. As the car entered the tower, temperatures rose about 5 to 6°C above ambient over the 20-sec period before the water was turned on. After the water was turned on, the temperature rose to about 90 to 95°C in 10 sec and then gradually dropped to about 54°C when the water flow stopped 1 min later. Temperatures continued to fall until they were again about 5 to 6°C above ambient when the car left 1 min later. The mean stack temperature at the sampling height was about 80°C.

Velocity measurements at Lorain were similar to those at DOFASCO. The velocity rose sharply, then plateaued for the quench period, and leveled off after the water was turned off. From data collected during various quenches, it appears that velocity may vary from point to point in the tower. Two figures show profiles of the tower with velocity ranges of 6.4 to 10.3 m/sec and 6.7 to 11.3 m/sec. During emissions tests, the average stack velocities ranged from 7.026 to 12.27 m/sec with an average for all tests of about 9.39 m/sec.

Moisture content of the emissions stream in percent by volume ranged from 22.1 to 55% with an average of 36.95%. This is a relatively low moisture content for the stack temperatures recorded at Lorain.

Particulate measurements: Particulate emissions were determined at Lorain for a baffled source using both clean and dirty water. Results were obtained for a total of 25 tests. Grain loadings and emissions per megagram of coke for each of these tests are presented in Table 10. As shown in the table, emissions from the tower when clean water was used as makeup ranged from 0.515 to 1.66 kg/Mg (1.03 to 3.22 lb/ton). Emissions from dirty water quenches ranged from 1.43 to 4.075 kg/Mg (2.86 to 8.15 lb/ton). Average emissions were 1.09 kg/Mg (2.18 lb/ton) for clean water tests and 2.23 kg/Mg (4.46 lb/ton) for dirty water tests (irrespective of greenness rating on the coke). These results are relatively high in comparison to other tests as previously discussed.

TABLE 10a. PARTICULATE EMISSIONS DATA--LORAIN TEST NO. 1 (METRIC)

Makeup Water	Test No.	Loading (mg/Nm^3)	Emissions (kg/Mg)
By-Products Plant	4B20	1,821	3.25
	5B50	1,627	2.60
	6B80	1,320	1.43
	7C50	1,608	1.80
	8C20	1,732	2.12
	9C80	2,380	2.04
	10D50	2,791	3.08
	11D80	1,725	2.07
	12D20	1,430	2.12
	13A50	1,217	1.60
	14A20	1,853	3.17
	15A80	3,295	4.08
	16C5P0	-	-
Clean River Water	1C8I	936	1.45
	3C2I	762	1.04
	1B5I	929	1.48
	2B21	831	1.25
	3B8I	966	1.61
	4D5I	888	1.09
	5D2I	590	0.800
	6D8I	588	0.675
	7A5I	824	1.34
	8A8I	387	0.515
	9A2I	524	0.785
	10MI	609	0.840
	12MI	744	1.32

TABLE 10b. PARTICULATE EMISSION DATA - LORAIN TEST NO. 1 (English Units)

Makeup water	Test No.	Loading gr/scf	Emissions (lb/ton)
By-products plant water (recycled)	4B20	0.796	6.50
	5B50	0.711	5.21
	6B80	0.577	2.86
	7C50	0.703	3.59
	8C20	0.757	4.25
	9C80	1.040	4.07
	10D50	1.222	6.15
	11D80	0.754	4.14
	12D20	0.625	4.23
	13A50	0.532	3.21
	14A20	0.810	6.34
	15A80	1.440	8.15
	16C5PO	---	---
Clean river water (recycled)	1C8I	0.409	2.90
	3C2I	0.333	2.08
	1B5I	0.406	2.96
	2B2I	0.363	2.50
	3B8I	0.422	3.22
	4D5I	0.388	2.18
	5D2I	0.258	1.60
	6D8I	0.257	1.35
	7A5I	0.360	2.67
	8A8I	0.169	1.03
	9A2I	0.229	1.57
	10MI	0.266	1.68
	12MI	0.325	2.63

Particle size distribution was also estimated in the same manner as the DOFASCO tests. Weight fractions for each sample train component for each test are presented in Table 11. One may assume that the cyclone catches particles and droplets greater than 10 μm in diameter. With this assumption, about 31% of the particulate captured from the dirty quenches is either greater than 10 μm or contained in droplets of greater than 10 μm in size. About 18% of the clean water particles are in that range. Since baffles are relatively effective for large particles, low loadings of large particles downstream of the baffles are expected.

Only limited total particulate data are available from the second set of Lorain tests conducted in 1978. These are presented in Table 12. It should be noted that these are preliminary numbers and should be used accordingly. Average emissions for the 11 clean water tests were 0.78 kg/Mg coke (1.56 lb/ton coke).

Average emissions for the four dirty water tests were 1.625 kg/Mg coke (3.25 lb/ton coke). Both of these values are substantially lower than corresponding averages from the first series of tests. In addition, the authors indicate that these values may be in error on the high side due to silicone grease and phthalate contamination found in the samples, which were believed to originate from the sampling train.

Organic emissions results--A total of four tests, two with clean water and two with contaminated water were planned for the first set of Lorain tests. However, one of the contaminated tests had to be discarded due to excessive plugging of the sample train. Results of the analysis for organic compounds are presented in Table 13. Data presented in this table indicate that emissions of all types of organic compounds were greater with clean than "dirty" water, even though the "dirty" water contained levels of organics that were an order of magnitude larger than levels in the clean water. Based on these few tests, the limited data indicate that water quality has little to do with the quantity of organic emissions from quench towers. This conclusion is opposite that drawn for particulate emissions. It was noted that the greenness ratings were low for the clean water tests. This phenomenon is also opposite that expected for high levels of organic emissions.

In addition to total organics, POMs were also quantified for the tests. These data are presented in Table 14.

Preliminary results are available from the second Lorain tests on polycyclic aromatic hydrocarbons (PAH) and benzene and total hydrocarbon. These preliminary results may be adjusted at a later date. Emissions for three PAH tests are presented in Table 15. Tests Nos. 5 and 7 are for clean water makeup and No. 14 is for by-products makeup. It is apparent that recycling by-products effluent as quench water produces significantly higher emissions than river water.

TABLE 11. PARTICLE SIZE DATA - LORAIN TEST NO. 1

Water source	Test No.	Weight Fraction Captured			
		Cyclone	Probe	Filter	Impingers
By-products effluent	4B20	0.279	0.195	0.156	0.369
	5B50	0.395	0.124	0.122	0.359
	6B80	0.402	0.293	0.139	0.166
	7C50	0.312	0.253	0.171	0.265
	8C20	0.403	0.182	0.165	0.250
	9C80	0.228	0.380	0.176	0.216
	10D50	0.371	0.432	0.085	0.112
	11D80	0.375	0.391	0.105	0.129
	12D20	0.275	0.368	0.157	0.200
	13A50	0.383	0.327	0.132	0.158
	14A20	0.294	0.454	0.085	0.167
	15A80	0.280	0.402	0.085	0.247
Clean river water	1C8I	0.105	0.780	0.017	0.098
	3C2I	0.114	0.814	0.021	0.051
	1B5I	0.108	0.835	0.005	0.052
	2B2I	0.052	0.843	0.039	0.066
	3B8I	0.241	0.625	0.009	0.125
	4D5I	0.152	0.637	0.010	0.201
	5D2I	0.156	0.774	---	0.070
	6D8I	0.081	0.751	---	0.168
	7A5I	0.497	0.386	---	0.117
	8A8I	0.174	0.783	0.003	0.039
	9A2I	0.157	0.735	---	0.109
	10MI	0.325	0.563	---	0.112
	12MI	0.208	0.731	---	0.061

TABLE 12. PARTICULATE EMISSIONS DATA - LORAIN TEST NO. 2

Water source	Test No.	Loading mg/m^3	Emissions kg/Mg
Clean river water	2B	692	0.940
	3	659	1.03
	4	734	0.920
	5	807	1.01
	6	515	0.765
	7	1,130	1.33
	8	716	0.840
	9	318	0.42
	10	346	0.44
	11	283	0.630
	12	478	0.70
By-products effluent	14	1,011	1.78
	15	1,216	1.69
	16	1,190	1.58
	17	900	1.45

TABLE 13. ORGANIC EMISSIONS SUMMARY - LORAIN TEST NO. 1

Type of organic compound	Contaminated water		Clean water	
	mg/m^3	kg/Mg	mg/m^3	kg/Mg
Aliphatic hydrocarbons	14.29	0.026	734.72	1.172
Aromatic hydrocarbons	ND	ND	NA	NA
Non-aromatic heterocarbons (esters, alcohols)	1.64	0.003	ND	ND
Aromatic heterocarbons (phenols, nitrites, phtalate, esters)	259.15	0.464	2,408.57	3.842
Aldehydes, esters, carboxilic acids, acrylate polymers	95.61	0.171	212.76	0.340
Keytones, amine salts, phosphines, isocyanate	32.80	0.0585	44.70	0.0715
Totals	403.49	0.7215	3,400.75	5.425

ND = Not Detected

NA = Detected but weight attributable to this compound not available.

TABLE 14. POM DATA - LORAIN TEST NO. 1

Component	Stack Test 11A(clean)		Stack Test 13A(clean)		Stack Test 16A(dirty)	
	mg/Mg	$\mu g/m^3$	mg/Mg	$\mu g/m^3$	mg/Mg	$\mu g/m^3$
Anthracene/phenanthrene	1.2	0.673	0.66	0.484	1.62	0.910
Methyl anthracenes	0.59	0.294	0.368	0.271	0.660	0.370
Fluoranthene	0.70	0.384	0.252	0.186	0.850	0.476
Pyrene	0.496	0.270	0.221	0.163	0.635	0.354
Methyl pyrene fluoranthene	0.37	0.194	0.227	0.167	0.48	0.270
Benzo(c)phenanthrene	0.452	0.246	0.214	0.158	0.510	0.286
Chrysene/ Benz(a)anthracene	0.461	0.251	0.233	0.172	0.700	0.392
Methyl chrysenes	0.035	0.019	0.024	0.018		
Dimethylbenz(a)anthracene	0.52	0.284	0.246	0.181		
Benzo fluoranthenes						
Benz(a)pyrene						
Benz(e)pyrene						
Indeno(1,2,3-cd)pyrene						

TABLE 15. PRELIMINARY PAH RESULTS FOR THE SECOND SET OF TESTS AT U.S.S. - LORAIN

	Clean Water Test No. 5		Clean Water Test No. 7		Dirty Water Test No. 14	
Species	Conc $\mu g/m^3$	Emissions g/Mg	Conc $\mu g/m^3$	Emissions g/Mg	Conc $\mu g/m^3$	Emissions g/Mg
Idene	ND		ND		69	0.121
Naphthalene	173	0.216	99	0.116	>6,846	>12.0
Benzothiophene	4.2	0.005	2.3	0.0027	937	1.64
Methyl Naphthalenes	82	0.102	25	0.030	1,631	2.87
Acenaphthylene/Biphenylene	31	0.040	11	0.013	1,892	3.32
Biphenyl	10.9	0.014	6.8	0.0080	345	0.60
Dimethyl Naphthalenes	135	0.169	25	0.029	352	0.615
Fluorene	70	0.087	35	0.042	2,190	3.85
Carbazole	ND		ND		470	0.820
Dibenzofuron/methyl biphenyl*	69	0.0875	18	0.022	1,274	2.23
Anthracene/phenanthrene	478	0.595	260	0.305	>4,005	>7.05
Diobenzothiophene	10	0.014	16	0.018	219	0.358
Methyl anthracenes	183	0.230	85	0.100	410	0.72
Fluoranthene	44	0.0545	31	0.036	918	1.65
Pyrene	38	0.048	25	0.034	737	1.29
$C_{16}H_{12}PAH$	ND		ND		46	0.0815
$C_{16}H_{12}PAH$	ND		ND		12	0.020
$C_{16}H_{12}PAH$	ND		ND		ND	
$C_{16}H_{16}PAH$	ND		ND		11	0.020
Methyl Fluoranthen Methyl Pyrene	20	0.026	13	0.016	120	0.211
Dihydrobenzofluorene	ND		ND		42	0.072
Chrysene/Benz(a)anthracenes*	11.4	0.014	89	0.104	88	0.155
Naphthobenzothiophene	ND		ND		2.3	0.0040
Methyl-chrysense	ND		ND		14	0.0242
Benzofluoranthene, benzo(e)pyrene Benzo(a)pyrene*	ND		ND		118	0.208
Perylene	34	0.105	ND		76	0.133
P-phenyl anthracene(IS)	ND		ND		ND	
7.12 Dimethyl Benz(a)anthrocene*	ND		ND		ND	
Methyl-benzo pyrenes	ND		ND		ND	
Dibenzo(c,g)carbazole*	ND		ND		ND	
3-methyl cholanthrene	ND		ND		ND	
Indeno(1,2,3-cd)pyrene	ND		ND		ND	
Benzo(ghi)perylene	ND		ND		ND	
Dibenzo(ah)anthracene*	ND		ND		ND	
Coronene	ND		ND		ND	
Dibenzo(al & ah)pyrenes	ND		ND		ND	
Total	1,443	1.802	745	0.875	22,844	39.9

ND = Not detected.
* Known carcinogens.

Of the compounds listed in Table 15, the following are classified by the Occupational Safety and Health Administration (OSHA) as known carcinogens:

Dibenzofuran/methyl biphenyl

Chrysene/benz[a]anthracene

Benzo[a]pyrene

7,12 Dimethyl[a]anthracene

Dibenzo[c,g]carbazole

Dibenz[a,h]anthracene

For clean water tests, average emissions of these compounds are 0.113 g/Mg coke 0.226 x 10^{-3} lb/ton coke). The emissions from the "dirty" water quench of these compounds totaled 2.595 g/Mg coke (5.19 x 10^{-3} lb/ton coke). This is opposite the results of the first set of tests.

In addition, preliminary data are available for BaP emissions from these tests. These results are presented in Table 16. Based upon these data, average emissions from the tests using clean makeup water are calculated to range from 0.103 x 10^{-3} to 0.229 x 10^{-3} kg of BaP/Mg of coke. The lower value was calculated by assuming the none detected tests to be 0; the higher value by assuming those tests to be at the detection limit. For tests using contaminated makeup water average emissions were 0.462 x 10^{-3} kg BaP/Mg of coke.

4.3 SUMMARY OF EMISSIONS DATA

This section summarizes the previously discussed particulate and hydrocarbon test results. A best estimate for total particulate emissions is developed. In addition, particle size estimates are discussed, and factors effecting emissions are analyzed. Estimates of total hydrocarbon and BaP emissions with respect to total particulate emissions are discussed.

4.3.1 Particulate Emissions

As indicated earlier, particulate emissions tests were conducted using a variety of methods including grab samples, greased plates, German Method VDI-2303 and a variety of suction capture systems. These methods have been divided into three categories: (a) suction sampling tests like EPA Method 5; (b) tests using VDI-2303; and (c) other sampling methods. Particulate loadings and total emissions as determined by suction systems are presented in Table 17. Data determined using the guidelines in VDI-2303 are presented in Table 18. All other test data are presented in Table 19. Because of the likelihood of sampling inaccuracy, the data in Table 19 are not considered to be of sufficient reliability to use to estimate quench tower emissions.

TABLE 16. BaP EMISSIONS AT U.S. STEEL - LORAIN

Test No.	Water quality[b/]	10^{-3} lb/quench[c/]	10^{-3} kg/Mg coke
2B	C	ND(0.41)	0 - 0.021
3	C	ND(0.44)	0 - 0.023
4	C	4.061	0.212
6	C	7.60	0.397
8	C	ND(0.34)	0 - 0.018
9	C	3.78	0.197
10	C	ND(0.57)	0 - 0.021
11	C	ND(0.87)	0 - 0.045
12	C	ND(0.53)	0 - 0.028
15	D	7.67	0.400
16	D	10.1	0.527
17	D	4.41	0.230
5cy[a/]	C	2.66	0.139
5FP	C	ND(0.31)	0 - 0.016
5X	C	3.70	0.193
5 Total	C	6.36	0.332 - 0.348
7cy	C	ND(0.46)	0 - 0.024
7FP	C	ND(0.40)	0 - 0.021
7X	C	ND(0.51)	0 - 0.027
7 Total	C	ND	0 - 0.072
14cy	D	7.37	0.385
14FP	D	2.62	0.137
14 Total	D	13.2	0.689

a/ cy = cyclone; FP = filter and probe; X = XAD resin

b/ C = river water makeup; D = by-products effluent makeup

c/ ND = none detected. Values in parentheses are detection limit for that test with calculation based on data supplied by A. D. Little.

TABLE 17. SUCTION SAMPLING RESULTS

Location	No. of Tests	Concentration mg/Nm³ Min	Max	Avg	Emissions kg/Mg Min	Max	Avg	Comments
Armco, Houston	4	98.4	144	121	0.135	0.195	0.162	Baffles (3 rows) (clean makeup)
Bethlehem, Lackawana	2	420.3	446.2	432.4	-	-	0.49 a/	Low baffles (dirty makeup)
Bethlehem, Tonawanda	1	-	-	252	-	-	0.5	No control (clean makeup)
Kaiser, Fontana	3	43.0	89.2	72.3	0.055	0.250	0.16	Baffles g/
Baird and Scottish Ltd. b/					0.153	0.765	0.765 b/	No control g/
					0.3560	0.380	0.380 b/	Baffles g/
U. S. Steel, Lorain I	12	387	966	721	0.378	1.18	0.775	Baffles with clean makeup
	12	1,220	3,290	1,900	1.04	2.98	1.76 c/	Baffles with dirty makeup
U. S. Steel Lorain II	11				0.304	0.975	0.610	Baffles with clean makeup
	4				1.06	1.30	1.19 c/	Baffles with dirty makeup
DOFASCO	9	189	299.5	268.8	0.159	0.336	0.225	Baffles (clean makeup)
	2	193	316.7	254.7	0.179	0.190	0.184	Baffles and sprays (clean makeup)
	6	222	565.8	328.8	0.202	0.364	0.262	Baffles and once through bay water
Margam Works, d/ Steel Co. of Wales	23	-	-	-	-	-	0.042 d/	No control g/
	20	-	-	-	-	-	0.022	Screens g/

a/ Makeup water was larry car scrubber effluent.

b/ Data given in text in lb/quench. An estimate of 10 tons of coke per quench was used to calculate emissions. The values of 0.765 and 0.380 were used as averages since they were most representative of normal coking operations.

c/ By-products process water used as makeup.

d/ These data were taken using a thimble and account for emissions only from the front section of the tower. These estimates are lower than those obtained using greased plates at the same tower.

g/ Source of makeup water was not specified.

TABLE 18. VDI-2303 QUENCH TOWER DATA

Installation	Emission w/o control (g/Mg of coke)	Control measure	Controlled emissions (g/Mg of coke)
Jacobi Ost[a]	260	Spray during pushing	120
	260	Spray during push and 30 degree slope Otto baffles	70
	260	Spray during push and 30 degree slope Otto baffles and spray in plume	50
Kaiserstuhl A/B[a]	400	Nathaus KG baffles	60
Minister Stein[a]	250	Nathaus KG baffles	40
Koenigsborn[b]	200	Backspray	160
Grimberg[b]	300	Backspray	50
Minister Stein[b]	160-200	Backspray	40-100
Erin[b]	130-200	Backspray	30-120
Hansa[b]	60-120	Backspray	-
Friedrich Heinrich[b]	80	Backspray	30
Pforzheim[b]	-	Backsprays and multiple baffles	20
Koenigsborn 3/4[c]	200-250	Fa. Carl Still's quenching stack baffles	34-35
Minister Stein No. 1[c]	200-250	Fa. Carl Still's quenching stack baffles	34-42
Minister Stein No. 2[c]	200-250	Fa. Carl Still's quenching stack baffles	15
Jacobi No. 1[c]	200-250	Fa. Carl Still's quenching stack baffles	14.3-16.7
Osterfeld[c]	798	Two rows Fa. Carl Still's quenching stack baffles	37
Unknown[d]	260	Two rows of alternating baffles 60° from horizontal	75

a/ Data contained in letter from Dr. C. Otto, of McKee-Otto Engineers, to Mr. Naum Georgieff of EPA, dated July 1977.

b/ Data supplied by Ruhrkohl to Dr. C. Otto. Transmitted to Mr. Naum Georgieff of EPA in letter dated July 1977.

c/ Data supplied in a letter from Mr. H. Weber, of Carl Still Corporation, to Mr. Naum Georgieff of of EPA, dated June 8, 1977.

d/ Data developed by V. Masek (reference 41).

TABLE 19. DATA FROM OTHER SAMPLING METHODS

Source	Grain Loading (mg/m^3)	Uncontrolled Emissions (kg/Mg) Coke	Controlled Emissions (kg/Mg) Coke	Control Measure
Margam Works[a] Steel Co. of Wales	-	0.090	0.014	Wedgewire Screen
USSR (Plant[b] unknown)	-	0.0830	-	-
CF and I[c]	12-16	0.044	-	None[d]
	8-12	0.031	-	None
U.S.S. Clairton[a]	-	0.25	0.03	Baffles
Poland (Plant[b] unknown)	-	0.3	-	May be controlled, but control device unknown

a/ Greased plate test
b/ Test method unknown
c/ Grab sample
d/ By-products effluent used as makeup

Data from those tests using VDI-2303 suggest that uncontrolled emissions from quench towers range from 0.06 to 0.795 kg/Mg (0.12 to 1.59 lb/ton) of coke with an average of about 0.25 kg/Mg coke (0.5 lb/ton coke).[53] However, based on data from quench towers tested using suction sampling methods, this value appears to be low.

Of the towers tested using suction sampling systems, only two have no baffling systems (disregarding the extremely low results for the Margam tests). A single test at Bethlehem, Tonawanda determined emissions to be about 0.5 kg/Mg coke (1 lb/ton coke).[47] MRI's estimates based on a test using a cyclone capture device at Baird and Scottish Steel, Ltd. in England indicated emissions to be 0.765 kg/Mg (1.53 lb/ton coke).[38] However, this was based only on the amount captured in the cyclone. If it is assumed that this cyclone captured 90% of the materials as indicated by the amounts captured in the probe and cyclone in the Tonawanda tests, total emissions are probably in the range of 0.85 kg/Mg coke (1.7 lb/ton coke).

* * *

Several factors can affect the level of emissions from quench towers. These include the use of baffles to minimize emissions, use of clean water versus byproducts plant effluent as makeup water, and quality of coke (primarily greenness). Each of these aspects is discussed with respect to test data in the following sections. Data on particle size are then presented. Finally, estimates of total particulate emissions are developed.

4.3.1.1 Effects of Baffles on Emissions - Two types of data are available on baffled towers. Four sets of data compare emissions with and without baffling, while tests at five plants identified total emissions downstream from baffles.

The four sets of data comparing emissions before and after baffling are: (a) the series of tests performed at Bairds and Scottish Steel, Ltd., using suction sampling; (b) V. Masek's tests at a Czechoslovakian plant; (c) German test data for Carl Still towers; and (d) Fullerton's tests at U.S. Steel - Clairton. Results are discussed below.

Two test phases were conducted at Bairds. During the first phase under normal operating procedures, two rows of baffles inclined at 70 degrees from the horizontal reduced emissions from 6.95 to 3.5 kg per quench (15.3 to 7.7 lb per quench), a reduction of about 50%.[38] Estimates of fractional efficiency by particle size for these tests are presented in Table 20. During the second phase, four types of baffling arrangements were used; wooden baffles located either directly above the sprays or just below the parapet, and corrugated asbestos baffles located in the same two positions. The only effective arrangement was with wooden baffles located high in the tower. These had a 63% collection efficiency. The other three arrangements all had less than 25% efficiency.[47]

TABLE 20. BAFFLE EFFICIENCY FOR VARIOUS PARTICLE SIZES[15/],[a/]

Particle size (μm)	Unc. emissions (kg/quench)	Cont. emissions (kg/quench)	Coll. efficiency (%)
0-53	0.7	0.48	32
53-76	0.35	0.20	43
76-104	0.41	0.24	42
104-152	0.58	0.35	40
152-211	0.77	0.46	41
211-295	1.08	0.61	44
295-422	1.23	0.56	55
422-599	1.14	0.41	64
> 599	0.47	0.20	59

a/ These data are for baffles placed 20 degrees from the vertical and 3.0-4.6 m/sec emissions velocity. Authors indicate that data may not be sufficient to determine fractional collection efficiency.

It should be noted that the 3.81-cm cyclone used may have collected only the large diameter particles. However, even if this is the case, if we assume that 90% of the particles were greater than 10 μm in diameter,* the cyclone should have captured all of these particles. This would result in minimum collection efficiencies for the two tests of data of:

$$100\ (0.9 \times 0.50) = 45.0\%$$

$$100\ (0.9 \times 0.63) = 56.7\%$$

Additional results on the effect of baffles were obtained by V. Masek of Czechoslovakia using German Method VDI-2303. On an uncontrolled tower, emissions were on the order of 259.89 g of dust per megagram of coke.[41/] He found the best type control to be two rows of opposing baffles with a slope of 30 degrees from the vertical. Emissions from a tower with these baffles were 75.00 g/Mg of coke, an emissions reduction of about 71%. Emissions with respect to particle

* Based on discussion of Bethlehem, Tonawanda data in Section 4.3.1.1.

size are presented in Table 21.[41] These efficiencies are questionable in that the 87% efficiency for particles less than 5 μm in diameter is certainly not expected. The method by which the particle sizing was done was not specified in Reference 41, so it is difficult to assess the validity of the results.

TABLE 21. BAFFLES EFFICIENCY WITH RESPECT TO PARTICLE SIZE[41]

Particle size (μm)	Unc. emissions (g/Mg)	Cont. emissions (g/Mg)	Efficiency (%)
0-5	6.622	0.8625	87
5-100	55.18	16.84	69
100-200	67.05	23.96	64
200-300	72.32	20.29	73
300-400	52.72	11.66	78
400-500	5.791	1.388	76

Emissions data are also available from Germany which compare baffled and nonbaffled emissions for two types of baffles. Two plants had results for Nathaus KG baffles indicating uncontrolled emissions of 400 g/Mg coke and 250 g/Mg of coke with controlled emissions of 60 g/Mg coke and 40 g/Mg of coke, respectively.[53] These represent an 84 to 85% reduction in total emissions. It should be noted that these levels of uncontrolled emissions are lower than most U.S. tests indicate. Again, this probably is a shortcoming of the VDI sampling method.

Only one of the plants using Carl Still baffles had actual test data for uncontrolled emissions. Tests showed emissions at Osterfeld to be 798 g/Mg coke (1.6 lb/ton coke). Two rows of Firma Carl Still's baffles reduced emissions to 37 g/Mg (0.074 lb/ton coke), a reduction of about 95%. Based on estimates of uncontrolled emissions, other towers had reductions ranging from 74 to 94% for single rows of baffles. It should be noted that these data are from tests utilizing methods suggested in VDI Guidelines 2303. Validity of these data has not been determined during this study.

Using greased plate tests, R. W. Fullerton determined efficiency for a single row of 45-degree baffles to be in the range of 85 to 90% effective in reducing emissions.[43] However, size analysis of Fullerton's capture emissions indicated that 97% of those emissions captured were greater than 75 μm in diameter. This does not agree with other data (U.S. Steel - Lorain; Bethlehem, Lackawanna) and indicates that most small particles probably escaped capture. Hence, this is a measure only of capture efficiency for large particle emissions.

Data from baffled towers indicate efficiencies ranging from 50 to 95% for various baffle arrangements. Data are insufficient to determine an explicit efficiency for any baffle arrangement. However, based on available data, we can estimate that any single row of baffling inclined from 30 to 45 degrees from the vertical will probably be only 50 to 60% efficient.

Data are available from five baffled quench towers in the United States and Canada. These data are among the most reliable found during this study. Of these towers, four have only a single row of baffles. The emissions in pounds per ton of coke for these four towers are:

Bethlehem (Lackawanna) 0.49 kg/Mg (0.98 lb/ton)[48]

Kaiser 0.155 kg/Mg (0.31 lb/ton)[44-46]

U.S. Steel - Lorain (clean water) 0.685 kg/Mg (1.37 lb/ton)[52]
(dirty water) 1.99 kg/Mg (2.98 lb/ton)[52]

DOFASCO 0.243 kg/Mg (0.486 lb/ton)[51]

Armco, Houston, has a series of three horizontal rows of baffles. Emissions there totaled 0.162 kg/Mg coke (0.325 lb/ton coke).[50] It should be noted that the emissions from Bethlehem (Lackawanna) are also from a tower using dirty makeup water. Since the effects of dirty makeup water will be discussed separately in a later section of this report, we will not consider the Bethlehem and Lorain dirty water tests at this time.

Looking just at the clean water tests, it can be seen that U.S. Steel - Lorain had emissions significantly higher than any of the other three plants. This might be explained by the fact that the quenching process at Lorain is the patented LO-MO® process. Industry personnel have indicated that this is a more violent process than normal quenching. Hence, it may cause increased fracturing and droplet formation. More importantly perhaps, the test data presented in Table 22 show that the velocities at Lorain are the highest of any tests at other plants, which might lead to higher particle and droplet entrainment. Thus, the emissions at Lorain can be considered representative for a narrow quench tower utilizing the LO-MO® process. If we assume the baffles are 50 to 75% efficient, emissions from an unbaffled Lorain-type tower, using clean makeup water, are estimated to be in the range of 1.35 to 2.7 kg/Mg coke (2.7 to 5.4 lb/ton coke).